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CAPACITY-STRETCHING TECHNICAL CHANGE: SOME EMPIRICAL AND THEORETICAL ASPECTS

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CONTENTS

1. INTRODUCTION AND OBJECTIVES

This paper has a dual origin in (i) some emprical studies of technological change in Latin American steelplants carried out by the BID/CEPAL Technology Research Programme (see Maxwell 1976 1/, Dahlman & Valadares, 1978 2/, and Perez Aceves & Perez y Peniche, 1978 3/, and (ii) a theoretical and review paper by Teubal, 1978 4/, also written for the BID/CEPAL Programme, in which one of the aspects proposed is a model of output increasing innovations.

The topic drawn from both sources, and developed in preliminary form in the present paper, is the nature and significance of "capacity stretching" in industrial plants.

This term refers to processes through which the production capacity of plants is increased in small, incremental steps, without the requirement for large new investment or replacement programmes. Certainly, some replacement investment or complementary investment may be involved. However, most of the plant and its equipment is left recognisably the same as before, and no thorough-going revamp is executed. Yet the result is an incremental boost in capacity. If many such incremental steps occur, intermittengly of continuously, one can speak fo the "stretching" of a plant's capacity over time.

Empirically, it appears from the steelplant studies mentiones above, and from several empirical studies in the BID/CEPAL series, dealing with firms in other industries -see J. Katz etc. al. 1977 5/, Perez and Perez 1978 6/, F. Sercovich 7/, J. Fidel and J. Lucângeli 8/- that capacity stretching is quite a widespread phenomenon in Latin American industrial plants. There is also some evidence in the industrial-economics literature from developed countries to suggest that plant capacity-stretching may be common in advanced economies too. 9/

Nevertheless one has to search hard in order to "piece together" from economics literature a systematic empirical description or theoretical articulation of capacity-stretching. Most standard economics text treatments of the production plan of the firm do not mention it at all.

This does not mean the phenomenon has passed un-noticed by economists. For example, important theoretical as well as empirical aspects of capacity stretching have been signalled by authors such as Enos 10/, Hollander 11/, Chenery 12/, Andrews 13/, Hughes 14/, Levin 15/ and Sercovich 16/ (the latter in the BID/CEPAL Programme), and undoubtedly there are many other contributions which could be found by a systematic literature search.

However, it is obvious that most "theory of the firm" literature and "technical change analytics" literature uses the notion of plants that have a fixed capacity. A notable example comes from Salter's well known analysis of technical change, where it is assumed that "once a plant is constructed, no changes occur in the input of factors of production required to produce the original designed 'normal capacity output'... and that to reduce the quantities of labour, materials and fuel needed to produce a given output requires a different technique, and this is only possible with a new outfit of capital equipment" 17/. Later on in his analysis Salter points out that the assumption of an "inflexible technique embodied in an indivisible plant" is unrealistic and he discusses the piecemeal modernization of plants via replacement of individual machines in them. 18/ But even with this important addition to his analysis, Salter's plant still always operate at unchanged 'normal capacity output'. Although variable production costs are assumed to fall at the plant due to piecemeal replacements, capacity is assumed to remain the same.

A second reason why the subject of capacity-stretching seems to be somewhat "lost from view" in the economic literature is that even when stretchin is explicitly recognised it is usually viewed as merely a mechanis for achieving cost-reductions via increases in scale of output rather than as a pehnomenon or objective in its own right. A good example of this comes from the celebrated empirical study of technical change in rayon plants by S. Hollander in which attention was explicitly restricted to technical changes aimed at producing reduction in the unit cost of rayon, and in which capacity-stretching technical changes were termed "indirect, cost-reducing technical changes". 19/

A third reason which can be tentatively suggested to explain the relative lack of literature on capacity-stretching is that economic analysis has tended to concentrate on either the "short-run" adjustment of the firm to changing factor or product prices (when machinery and technique is assumed unalterable) or on the "long-run" adjustment of the firm when, in principle, enterpreneurs are free to adjust not only their variable factors but also all their fixed factors of production as well in search of the least cost way of producing their planned long-run output. For instance standard expositions of the 'production plan' in microeconomics texts nearly always show both short-run and long-run average cost and marginal cost curves. But they do not usually show "medium run curves', which loosely speaking refer to all those intermediate situations in which the entrepreneur may undertake some alterations or additions to his existing capital sotck and organization, but when he is still greatly constrained by those elements within this stock or organization which, by their inherent nature, are the most difficult to alter quickly -i.e. that are the most "fixed". It is our belief, advanced in the paper, that capacity stretching falls within the broad category of "medium-run adjustments" in industrial plants- and possibly because this category is so broad and does not admit of such precise delineation as the short-run and long-run equilibrium situations, it has not been that much explored.

Now for the specific aims and scope of the present paper: to start with, in Section 2 that follows, some brief remarks are made on the definitions of production capacity and capacity stretching -the aim being to explain our use of these concepts-, then, in Part I on 'Empirical Findings' the aim is to pull together and synthesize the various empirical results on capacity stretching reached in the BID/CEPAL steelplant case-studies. In particular, Sections 3 to 7 in Part I deal with the extent, frequency, and causes of the capacity-stretching projects observed in the plants, as well as the methods used to bring capacity-stretching about. Section 8 summarises these empirical findings.

In Part II, 'Interpretation and Models' the aim is to provide some articulation of these findings. In particular, Section 9 explains how four prominent technological characteristics of steel plants provide frequent stimuli to capacity stretching projects. Section 10 portrays capacity-stretching as a medium-run adjustment by firms to a demand increase, constrating it with both short-run and long-run adjustments. Section 11 contrasts capacity-stretching to "pure" cost-reducing technical changes. Section 12 develops a model which illustrates several parameters involved in the making of an optimal choice by firms as between stretching the capacity of its plant or conventional expansion when faced by an increase in demand.

A point we wish to emphasize is that this is very much a working paper. It is an assembly of "results so far" whose main purpose is to act as a way-stage contribution towards a more developed and refined treatment of the capacity stretching theme.

For this reason, at the end of our summary of the paper in Section 13, we briefly note some lines of further development which we believe would be worth exploring in order to develop the topic more adequately. Quite probable some, if not all, of these further lines have already received some investigative effort and had results published in the literature. In that sense we hope this paper will stimulate readers and future authors interested in this theme to "unbury" from the literature the many contributions realting to capacity-stretching which we believe are there, expressed in the vocabulary of 'firm expansion paths', 'economies of scale', 'latent economies of scale', 'cost-reducing technical changes', 'plant upgrading and modernization', 'incremental technical change', and so on.

References to Section 1

1/ P. Maxwell, Learning and Technical Change in the Steelplant of Acindar S.A. in Rosario, BID/CEPAL/BA/18, December, 1976.

2/ C. Dahlman and F. Valadares, From Technological Dependence to Technological Development: The Case of the USIMINAS Steel Plant in Brazil, BID/CEPAL/BA/40, October, 1978.

3/ L.A. Pérez Aceves and J. Pérez y Peniche, Decisiones Tecnológicas al Nivel de Empresa, El Caso de Altos Hornos de México S.A. Monografía N°24, BID/CEPAL, October, 1978.

4/ M. Teubal, Innovation and Development, BID/CEPAL/BA/52, April, 1979.

5/ J. Katz et. al., Productividad, Tecnología y Esfuerzos Locales de Investigación y Desarrollo, BID/CEPAL/BA/23, March 1978. See p. 77 for conclusion relevant to our topic, and earlier for detailed empirical evidence of capacity stretching.

6/ L.A. Pérez Aceves and J. Pérez y Peniche, Análisis Microeconómico de las Características de Cambio Tecnológico y del Proceso de Innovaciones: El Caso de Furfural y Derivados S.A., México, BID/CEPAL, June 1978, see pp. 102-105, and earlier empirical results.

7/ F. Sercovich, Design Engineering and Endogenous Technical Change: A Microeconomic Approach bsed on the Experience of the Argentine Chemical and Petrochemical Industries, BID/CEPAL, August, 1978.

8/ J. Fidel and J. Lucángeli, Objetivos Económicos y Conducta Tecnológica de una Empresa Petrolera Estatal en la Etapa de Refinación, Versión preliminar BID/CEPAL, Mimeo, see p. 34 last paragraph.

9/ See B. Gold in "Productivity Measurement, Problems and Methods", Ch. 3 of S. Eilon, B. Gold, J. Soesan, Applied Productivity Analysis for Industry, Pergamon Press, Oxford, 1976.

10/ J. L. Enos, "A Measure of the Rate of Progress in the Petroleum Rrefining Industry", Journal of Industrial Economics, June, 1958.

11/ S. Hollander, The Sources of Increased Efficiency, MIT Press, 1965.

12/ H. Chenery, "Overcapacity and the Acceleration Principle", Econométrica, January, 1952, Vol. 20, No. 1.

13/ P.W.S. Andrews, Manufacturing Business, Macmillan, see Ch. III Costs of Production: Part 1, The Effects of Changing Outputs, especially pp. 87-95.

14/ W. Hughes, "Scale Economies and Electric Power", in W. Capron Ed., Technical Change in Regulated Industries, Brookings, Washington, 1971.

15/ R. Levin, Technical Change, Economies of Scale and Market Structure, Yale University, Ph.D., 1974.

16/ F. Sercovich, Design Engineering..., op. cit.

17/ W. Salter, Productivity and Technical Change, Cambridge University Press, 1960, p. 51.

18/ W. Salter, ibid. pp. 83, 84.

19/ S. Hollander, op. cit.

to denote what Gold calls "practically sustainable capacity at present". Moreover Sercovich underlines the distinction between the "nominal capacity" of a plant and its "effective capacity".

Nominal capacity a/ is the capacity that was contracted for by the owner upon purchasing the plant. It does not alter throughout the plant's lifetime except in the case of major new investments in the plant or replacements in its main process units, in which case the plant is considered to have "changed its identity" (i.e. become a different plant).

Effective capacity, on the other hand, can and usually does vary throughout the life of a plant: thus, during the "start-up" period of plants, effective capacity usually begins well below nominal capacity (see Baloff 1963 3/), and it is the main purpose during start-ups for a plant personnel to learn how to gradually speed up the process and improve their own capability in handling it so that its effective capacity will reach its nominal capacity.

But even when the start-up process is finiches (and a "steady-state" effective capacity is approximated) this may not last long, because effective capacity is liable to important fluctuations and systematic variations in both a downwards and an upwards direction under the impact of changed processing conditions.

Given this variability through time of effective capacity, one interesting theme not taken up in this paper - concerns the circumstances in which effective plant capacity, after startup, may lie below nominal capacity. (See Sercovich's treatment of this topic 4/, and also Eckhaus 5/.)

Our theme, in contrast, concerns the way that higher-than-nominal capacities may result from engineering and learning efforts made in plants after their start-up period is over. b/

In fact we shall focus on the cumulative impact of such engineering and learning efforts in leading to what we call the "stretching" of plant capacities (i.e. of effective capacities) over time - as well as enquiring into the determinants of these engineering and learning efforts.

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a/ Nominal capacity is frequently referred to as "rated capacity", or "design capacity". In this paper, all three terms are considered to have identical meaning, and the term nominal capacity will be used.

b/ It can happen that nominal capacity gets rated "conservatively" by the supplier upon delivering the completed plant so that output at the end of the start up period, and in normal working conditions, already exceeds the contractually promised levels without post-start-up engineering effort having been put in. However we shall not be exploring the empirical incidence of this in the present paper, and will usually assume that effective capacity at the end of the start up period corresponds fairly closely to nominal capacity - so that subsequent increases in effective capacity can then be atributed largely to post-start-up engineering efforts at the plant itself which result in disembodied technical changes in the plant or in embodied technical changes implying only low levels of additional capital investment.

In our empirical account that follows, which is based on evidence from several latin American steelplants, we shall regard as evidence of "stretched" capacity the achievement of higher than nominal capacity levels from plants, or from particular equipment units within plants, provided that these higher levels were not secured as a result of substantial new investment in the units or plants concerned.

But what constitutes "substantial" new investment? A convention could be adopted that the sum total of new investments made to modify a unit should not exceed X% of the original capital equipment invested in it. However we prefer to leave the matter less sharply defined that this, and will usually interpret all changes that do not actually replace or add main process units in our steelplants as "minor" changes which in turn can be considered to involve only minor, not substantial new investment. a/

So much, then, for the preliminaries. We now turn to look at some of the empirical research findings.

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a/ Sercovich's criterion is similar to ours thouth its wording seems to limit the size of the investments rather more strictly. Thus for Sercovich, the concept of effective capacity admits "the contribution of all those plant engineering efforts which have borne fruit up to the time when the calculation is made", and includes "those limited complementary investments which are linked with plant engineering efforts". On the other hand, the concept of increased effective capacity does not include changes of capacity "due to significant additional investments in fixed assets made after the start up of the plant". 6/

Note to Sections 3 to 8

In Sections 3 to 8 we often refer in footnotes to the case studies. These are denominated as follows:

Acindar, Rosario Report, (1976) = Philip Maxwell, Learning and Technical Change in the Steelplant of Acindar S.A. in Rosario, Argentina, BID/CEPAL BA 18, December 1976.

Acindar, Rosario Report (1978 Version) = Philip Maxwell, First-best Technological Strategy in an "Nth-best" Economic Context, BID/CEPAL BA 26, April 1978.

Acindar Report (Draft Thesis Version) = Philip Maxwell, "Learning and Technology Policy in Developing Countries A Case Study based on the Experience of the Argentine Steel Firm, Acindar S.A. 1943-1978", Draft D. Phil Thesis, Buenos Aires 1980.

USIMINAS Report = C. Dahlman and F. Valadares Fonseca, From Technological Dependence to Technological Development: The Case of the USIMINAS Steelplant in Brazil, Vols I and II, Working Paper 21, BID/CEPAL/PNUD, October 1978.

Colombia Steel Industry Report = G. Puerta, El Desarrollo Tecnológico en la Industria Siderúrgica en Colombia, (Technological Development in the Colombian Steel Industry), Working Paper 26, BID/CEPAL/PNUD, April 1979, Spanish.

AHMSA Report = L.A. Pérez Aceves & J. Pérez y Peniche, Decisiones Tecnolígicas al Nivel de Empresa. El Caso de Altos Hornos de México S.A., (Technological Decisions at the Firm Level. The Case of Altos Hornos de México S.A.), Working Paper 24, BID/CEPAL/PNUD, October 1978, Spanish.

3. EXTENT OF CAPACITY-STRETCHING OBSERVED IN STEELPLANTS

One of the main findings reported in the series of BID/CEPAL Steelplant studies concerns the extent to which the effective capacity of many of the existing installations in the sample of plants was "stretched" -often far beyond nominal capacity- as a result of experience gained in operating these installations and the technical changes introduced in them.

To illustrate this finding, we collect in Table 1 below some figures on the extent of capacity stretching observed in the USIMINAS, Acindar, AHMSA and Acerías Paz del Río plants in different kinds of steelmaking units within these plants.

The feature which clearly emerges is the great extent to which the effective capacity of the units shown in the table was stretched beyond nominal capacity. These increases ranged from effective capacity reaching 25% above nominal capacity to reaching over 130% above nominal capacity, impressive by any standards.

The 'novelty' of these results is not in their documentation of the existence of capacity-stretching. For example, years ago both Enos (1958) 1/ and Hollander (1965) 2/ drew attention to the output increases that could be obtained from largely unchanged plants in the fields of petrochemical and rayon plants respectively. Rather, if there is novelty in the results, it lies in the great quantitative significance that capacity-stretching seems to have had in these particular steelplants that were examined in different Latin American countries.

Interestingly, there is rather little written in the large economics literature on the steel industry about this capacity-stretching phenomenon, even in the literature dealing with economies of scale. 3/ One of the exceptions to this rule is Rosegger (1975) 4/ who noted that

> "An additional element of expansion was provided by the frequently remarkable increases in the rated capacities of existing plants through accumulation of smaller technological improvements and through "learning-by-doing". Up-ratings of ten to fifteen percent over a five year span are not unusual. They constitute another variable in a more dynamic view of the determination of plant sizes and the achievement of targeted final outputs, further modifying the concept of optimal capacities"..............."If the history of iron and steel-works in developed countries is any guide, continuous technological changes and the concomitant creation of incremental capacities at individual stages can be regarded as the rule rather than the exception"

The results obtained in the sample of Latin American plants strongly support these views of Rosegger's. But whereas he talks of upratings of up to fifteen percent over a five-year time-span, we have here got cases where much larger percentage increases in effective capacity were obtained, for example up to 130% over a six to seven year time-span in the case of USIMINAS's first two blast furnaces and first steel shop, and 66% to 130% in Acindar's steelmaking and rolling units over periods ranging from 7 to 29 years.

Table 3.1 Extent of capacity stretching observed in different plants and types of equipment

Type of Equipment	Plant and Units	Time Period	Nominal capacity of the Units at Beginning of Period	Efective Capacity Reached at end of Period	% Capacity-Stretching
Sinter strands	USIMINAS Original sinter plant	1967-73	770 000 tons/year a/	1 544 000 tons/year b/	101%
Coke ovens	USIMINAS Original coke planta	1970-73	507 000 tons/year a/	634 233 tons/year b/	25%
Blast furnaces	USIMINAS Furnaces 1 and 2	1966-73	504 000 tons/year a/	1 196 603 tons/year b/	137%
	ACERIAS PAZ DEL RIO Original furnace	1955-57	500 tons/day	840 tons/day	68%
Steel shops	*ACINDAR (Rosario)*				
	Siemens-Martin No.1	1944-73	2.75 tons/hour b/	6.32 tons/hour	130%
	Siemens Martin No.2	1949-73	3.65 tons/hour b/	6.32 tons/hour	72%
	Siemens Martin No.3	1964-73	3.80 tons/hour b/	6.32 tons/hour	66%
	AHMSA				
	Siemens-Martin No.1 to 3	1963-73	227 tons/day a/	410 tons/day d/	81%
	Siemens-Martin No.4 to 8	1963-72	393 tons/day e/	607 tons/day e/	54%
	USIMINAS BOF shop No.1	1966-72	500 000 tons/year a/	1 179 000 tons/year b/	134%
Rolling Mills	ACINDAR (Rosario)				
	Billet Mill	1955-74	8.30 tons/hour c/	19.00 tons/hour	129%
	Bar & Section Mill	1955-71	9.90 tons/hour b/	17.20 tons/hour	74%

Source: Derived from data in Acindar Report (1976), Usiminas Report, AHMSA Report and Colombia Steel Industry Report.

a/ These figures all refer to the nominal capacity of the units concerned. In every case this nominal capacity was actually achieved in the year shown at the beginning of the time-period. (i.e. the start-up period leading to the achievement of nominal capacity is excluded from the figures in the table).

b/ These figures all refer to the working capacity of the units after completion of their start-up period and refer to their capacity in use (i.e. when not "down" for maintenance or repairs).

c/ Ditto as for 2/ except that capacity is expressed in tons. per shift hour.

d/ Average per furnace for the three furnaces.

e/ Average per furnace for the five furnaces.

A central feature of all the cases of "capacity-stretching" that were observed, was that it was brought about mainly by the introduction and accumulation of minor, incremental technical changes to the existing equipment. Furthermore, this piecemeal, incremental capacity-stretching was usually brough about at relatively low investment cost compared to the investment in the original installations, ensuring that the investment costs per unit of extra (stretched) capacity were far below the investment cost per unit of nominal (unstretched) capacity. a/

As to the sources of the incremental technical changes introduced, these involved in all cases a combination of (i) carrying out changes suggested by the plant's actual experience in operating the units concerned, i.e. "learning-by-doing, and (ii) copying technical changes and improvements adopted elsewhere on similar equipment after suitably specifying and adapting them to the idiosyncratic local equipment and conditions in the plant concerned.

In any event the sheer cumulative extent and consequent economic significance of the capacity-stretching observed in this sample of plants justify an effort to look more closely into the factors which led to it.

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a/ Between 1967-68 and 1976-77, approximately US$ 7 million was invested by Acindar in its Rosario plant (the one mentioned in the table) compared to $22 million in its "Acevedo" plant and $27 million in its "Marathon" plant. The Investments in capacity-stretching projects in the Rosario plant were considerably less tahn $7 million, and appear to have accounted for less than half this total, Source of Data: Acindar Project Investment Approvals Archive.

In USIMINAS, the costs of "capacity-stretching" expansion from 500,000 tons nominal capacity to 1,200,000 tons was roughly estimated to have cost only US $ 40 millions compared to $ 261 millions in the original plant: see USIMINAS Report, Vol. 1, p. 186. Moreover, much of this $ 40 million involved technical assistance contracts and "what little investment occured was in small peripheral equipment such as sintering screens, roll crushers minor modification in major equipment units etc. "See USIMINAS Report, Vol. 1 p. 259.

In AHMSA, investments in the Siemens Martin steelshop after 1967 were minimal due to the priority given by the enterprise to investments in the forthcoming new BOF shop: see account in Section 4.3 below.

References to Section 3

1/ J.L. Enos, "A Measure of the Rate of Progress in the Petroleum Refining Industry", Journal of Industrial Economics, June, 1978.

2/ S. Hollander, The Sources of Increased Efficiency: A Study of the Du Pont Rayon Plants.

3/ On economics of scale in the steel industry, see A. Cockerill, The Steel Industry: International Comparisons of Industrial Structure and Performance, Cambridge University Press, 1974, especially Ch. VII; C.F. Pratten, Economics of Scale in Manufacturing Industry, University of Cambridge Department of Applied Economics, 1971.

4/ G. Rosegger, "On Optimal Technology and Scale in Industrialization: The Case of Steelmaking", Omega, Vol. 3, No.1, 1975.

4. EVIDENCE ON THE "PERVASIVENESS" OF CAPACITY-STRETCHING TECHNICAL CHANGE IN STEELPLANTS

A second finding from the case-studies is that capacity-stretching projects were 'pervasive".

By 'pervasive' what we mean is that (a) in each of the plants at any moment there were always an appreciable number of technical projects leading to stretched capacity going on in at least one production stage and often in two or three stages of the plant at the same time; (b) these projects usually represented a very significant fraction of the overall sett of technical change projects being undertaken in the plants at any particular time.

Moreover this 'pervasive' nature of capacity-stretching seems related to the observation that besides being frequently a priority objective of technical change in its own right, capacity-stretching was also noticed to have frequently occurred as a secondary objective, necessary condition or spin-off benefit of technical changes introduced with other main objectives in view (e.g. reducing unit costs, raising product quality, varying input-mix, etc.)

Some detailed evidence in support of these observations comes from the Acindar case-study where two samples of technical projects were examined to see what objectives motivated them:

i. A sampel of 30 important technical changes introduced in the Rosario plant during its lifetime, obtained by listing all the technical changes at the plant which were singled out for mention in the complete set of Acindar's annual reports to shareholders.

ii. A representative sample of 54 R&D projects carried out by Acindar in its Rosario, Acevedo and Marathon plants between 1970 and 1974 on which detailed information was available thanks to its having been specially prepared for an Argentine government agency.

Regarding the first sample of 30 important technical changes introduced in the Rosario plant, the reasons cited for these projects were;

Table 4.1 Objectives of 30 important technical changes in the Rosario Plant

Reasons given for introducing the technical changes	Number of technical changes carried out for these reasons(out of 30 technical changes)	
1. To increase production capacity	16	Analysis of individual reasons cited
2. To improve product quality	8	
3. To reduce unit costs	7	
4. To introduce new products	5	
5. To react tu fulloff in input quality	2	
1. and 3.	3	Analysis of multiple Reasons in those projects when more than one was cited
1. and 2. and 3.	2	
2. and 3.	1	

Source: P. Maxwell, Learning and Technical Change in the Steelplant of Acindar S.A. in Rosario, Argentina, Monograph 4, BID/CEPAL, Buenos Aires, December 1976, p. 79.

Table 4.2 Classification of the objectives of 54 Acindar R&D Projects

Classification of the objectives being sought	Number, and "Value" a/ of the projects in which this was the primary objective		Number and "Value" a/ of the projects in which this was either the primary objective or a secondary objective	
Objective	Number	Value, U.S.$	Number	Value, U.S.$
Launch of new products	21 (39%)	532,000 (19%)	21 (39%)	532,000 (19%)
Increased capacity for existing products b/	13 (24%)	1,304,000 (46%)	19 (35%)	1,793,000 (63%)
Reduced production costs	10 (19%)	703,000 (25%)	17 (31%)	818,000 (29%)
Improved quality of existing products	3 (6%)	35,000 (1%)	12 (22%)	492,000 (17%)
Easing of raw material supply restrictions	6 (11%)	251,000 (9%)	6 (11%)	251,000 (9%)
Better working conditions	1 (2%)	11,000 (0%)	3 (6%)	52,000 (2%)
Totals	54 (100%)	2,836,000 (100%)	54 (100%)	2,836,000 (100%)

Source of data: Calculated from data in Philip Maxwell, Implicit R&D Strategy and Investment linked R&D: A Study of the R&D Programme of the Argentine Steel Firm Acindar S.A., Working Paper 23, BID/CEPAL/PNUD, Buenos Aires, March 1979, plus suplementary data in Acindar's descriptions of these R&D projects as provided to the Argentine Sub-secretariat for Science and Technology.

a/ By the "value" of the project, what is meant is the total expenditure incurred by Acindar on its own labour input to these R&D projects, both skilled and unsilled labour. This figure gives a rough order of magnitude of the size of the project. However it is only rough because other project costs, such as on machinery, raw materials for pilot runs, expenditure on labour from outside firms etc., is not included.

b/ In only one of these projects was the addition of completely new capacity, rather than the stretching of existing capacity involved.

The most striking point to emerge is the high frequency of production capacity increase amongst the objectives for introducing technical changes.

It is also clear that some of the technical changes were specifically aimed at more than one objective simultaneously.

Coming now to the second sample - referring to the 54 R&D projects drawn from all three of Acindar's plants - the information of these is summarised in detail in Table 2.

The importance of capacity-stretching emerges very clearly indeed from this table. 24% of the projects had as their primary objective to increase production capacity for existing products (in every case except one by modifying existing equipment, not adding new units - i.e. by stretching capacity.) And fully 35% of all projects had increasing capacity included amongst their objectives as either the primary or a secondary objective. Furthermore, if we pay attention to the "value" of the projects and not just their number, the significance of capacity-increasing projects is seen to be further enhanced. For projects with capacity-increase amongst their objectives accounted for 63% of total project value. Moreover all of but one of these capacity increasing projects involved capacity-stretching and not duplication of facilities, and this one project was of low "value". So projects with capacity-stretching amongst their objective accounted for nearly 63% of the total value of all the projects in the sample.

So, analysis of both these samples of projects clearly supports our statements regarding both the pervasiveness of capacity-stretching projects and the importance of capacity-stretching as a primay objective for technical changes in its own right as well as a secondary or spin-off objective alongside technical changes undertaken for other reasons.

Without going into details here, these statements are also strongly corroborated by the material in the USIMINAS and AHMSA reports where innumerable examples of capacity-stretching change are given and where in both cases the need to distinguish capacity-increase as a separate objective of technical change distinct from (though related to) cost-reduction is emphasided.

Indeed the authors of the AHMSA study come to the conclusion that

> "AHMSA's objective (was) not profit maximisation but to provide the steel products demanded by the country's indistrialization" so that "AHMSA's technological efforts have been mainly directed to increasing production as the priority objective" rather than improving quality or reducing costs. a/

In the USIMINAS study, the authors present extensive evidence of capacity-stretching technical change in the original equipment installed by the firm, and explicitly state that it is "useful to distinguish an increase in production as a separate objective" of technical change. b/

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a/ AHMSA Report, p. 22, paragraphs 3 and 2.

b/ USIMINAS Report, p. 62.

In short the "pervasiveness" of capacity-stretching projects and the fact that capacity-stretching was often an independent objectivo in its own right were observed in all three of the plants.

5. ONE MAJOR INCENTIVE TO CAPACITY STRETCHING: THE DELAYING OR BLOCKING OF CONVENTIONAL EXPANSION

It emerged in the steelplant studies that one of the main incentives which actually led Acindar, USIMINAS and AHMSA to stretch the capacity of their plants to such a notable extent, was the blocking or delaying of these firms' "conventional" expansion plans. To see this requires us to dip briefly into the history of the plants:

5.1 Capacity-stretching in Acindar's Rosario plant

We start sith the case of Acindar's Rosario plant. Chart 5.1 below shows that, apart from the notable "stretching" in the capacity of the plant's first Siemens Martin furnace achieved in 1949-50 a/, the main "stretching" in the capacity of the plant's installation took place from the early 1960s onwards.

Indeed from 1963-64 through to the early 1970s, the chart shows how the capacity of the billet mill was stretched from around 10 to almost 20 tons per hour, whilst that of each of the Siemens Martin furnaces was stretched from around 3.5 to almost 6 tons per hour. b/

Considering the obsolete character of the Rosario plant's installations, and the fact that this capacity-stretching was achieved on a deliberately low, indeed "shoestring" investment budget, one can well understand the pride which the Rosario plant staff and indeed Acindar's management, had in this achievement.

Nevertheless, the key to understanding the story of capacity stretching in the Rosario plant is that Acindar's management never wanted or planned to keep the Rosario plant going so long, nor to ingeniously "stretch" its capacity in the way they did. Far from wanting to extend the life of the Rosario plant, Acindar's management wanted to scrap it ever since around 1953.

To see why, one must realise that the Rosario plant was built in 1943 at a time when the technology, the machinery and the skilled engineering help that would normally have been available from abroad to build a new steelplant was completely unobtainable, owing to World War 2 hostilities. So the plant got built thanks to the enterpreneurship and ingenious "do it yourself" technical improvisation organised by Arturo Acevedo, the founder of Acindar,

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a/ This was achieved by rebuilding the furnace to enlarge its inner volume, and by introducing the use of cupola furnaces to melt part of the scrap load. This part of the load could then be charged into the Siemens Martin furnace as "hot metal", thus speeding up both the charging and the melting cycle in the Siemens Martin.

b/ Rosario's first Siemens Martin furnace went into action in 1943. This was enlarged and modernized in 1949. A second Siemens Martin, closely similar to the enlarged and modernized first one was also installed in this same year (1949). Subsequently, a third Siemens Martin furnace, similar in size and design to the earlier two was added in 1963-64.

and his collegues. The result was a samll-scale, patched-up, high-cost plant based on antique, partly second-hand technology. Even after the war when the plant was extensively modernized (with an additional small Siemens Martin funace, cupola furnaces for charging hot metal, a new ingot casting bay and a new small-scale billet mill) the plant was still far from the technological forefront.

What was at the technological forefront was Acindar's second plant, built at Villa Constitución some 50kms. from Rosario, and started up in 1951. Quite unlike Rosario, the Villa Constitución plant was conceived right from the start as a large scale "high technology" plant. It consisted of a modern continuous Morgan combination rolling mill for bar, rod and skelp, with a capacity of 215,000 tons per year, making use of billets as its raw material. It was conceived by Acevedo as the first stage of what was to be a fully integrated plant at Villa Constitución. The idea was that iron ore would be delivered by river to the port at the Villa Constitución site; then blast furnaces, steel refining and primary rolling would turn the ore into pig iron, steel and finally into billets to feed the already-installed Morgan mill.

Within this scenario, one can easily see why the small-scale originally improvisèd Rosario plant (which also had the disadvantage of being on a small inland site) was relegated to second place in the minds of Acindar's directors. The obvious place to invest and expand was in Villa Constitución, not Rosario. That was why the scrapping of the Rosario plant was always considered as either desirable, or likely to happen soon once the "integration project" for producing billets in Villa Constitución actually got underway.

What interfered with Acindar's plans - and thereby prolonged the life the Rosario plant - was that the company's ambitious integration project for Villa Constitución ran into a succession of frustrating bureaucratic difficulties between 1953 and 1975 arising mainly from opposition on the part of the Dirección General de Fabricaciones Militares (General Directorate of Military Production).

Altogether six different specific projects put forward by Acindar - each of which would have led to the integration of the Villa Constitución plant - were stalled or eventually frustrated from securing the definitive official approval and financial guarantees that were needed to proceed. a/ It was not finally until 1975 that Acindar got the green light to integrate its Villa Constitución plant.

Thus Acindar's persistent desire to substitute high cost, small-scale billet production on Rosario's outmoded equipment by lower cost larger-scale billet production on new equipment in Villa Constitución was persistently frustrated during more than twenty years.

Furthermore these same hopes and uncertainties surrounding the integration project also ruled out the idea of a really thoroughgoing modernization of the Rosario plant - which would have involved scrapping the old Siemens Martin furnaces, ingot casting and billet rolling equipment in favour of one

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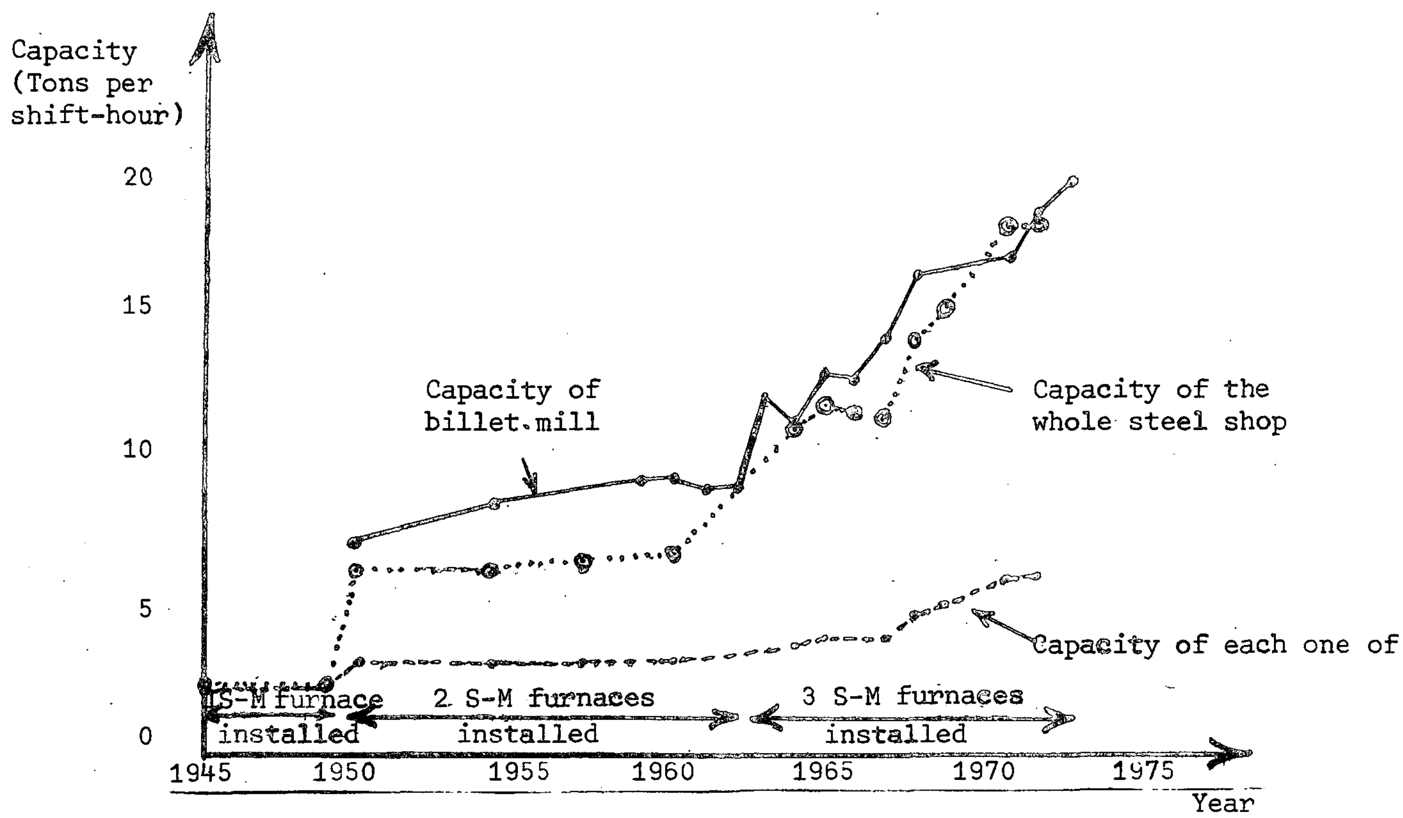
a/ See Acindar, Rosario Report (1978 Version) p.10.

Chart 5.1 Reconstruction of Capacity Stretching in Acindar's Rosario Plant 1945 - 1974



or two modern electric arc furnaces and continuous casting facilities. This modernization was not carried out because of the expectation on the part of Acindar's directors that they would, before too long, get the go-ahead to integrate their Villa Constitución plant and would thus be able to avoid all the disadvantages inherent in having to keep producing steel on the cramped Rosario site and then having to transport the billets 50 kilometers to Villa Constitución for rolling on Acindar's Morgan mill. In other words Acindar's directors never wanted to invest heavily in modernizing the Rosario plant because they always expected that the "superior" option of producing billets in Villa Constitución would open up, and that the expected future lifetime of the Rosario Plant would therefore be short. So the "planning horizon" for the Rosario plant was therefore (a) always uncertain, and (b) believed to have a sizeable probability of being extremely short. This explains why Acindar'd directors always sished to minimize any new investments in Rosario.

Finally, as we have shown in detail elsewhere, a/ all of the other natural ways for Acindar to have substituted Rosario's supply of billets by lower cost billets from other sources were also ruled out by the circumstances prevailing in the Argentine steel industry and economic context in successive years.

These above circumstances combined to repeatedly keep Acindar in a most curious position, consisting of:

1. Having to maintain in action over more than twenty years an obsolete plant which they had always wanted to scrap.

2. Having constantly to try to expand this plant's billet production from the early 60s onwards so as to contribute to a reasonable degree of utilization of capacity in Acindar's main rolling mill plant, which could not be kept adequatly provided by billets deriving from imports and domestic sources due to the frequently inadequate supply from the latter two sources.

3. Having to achieve these two goals whilst restricting investment in the old plant to a bare minimum.

In this position it was out of the question to completely modernize the plant, which would have cost far too much, or to purchase a whole additional new production line to work alongside the existing one, which would also have cost too much. b/ The main avenue open to Acindar was therefore repeatedly

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a/ See Acindar, Rosario Report (1978 Version) p.p. 6 to 11.

b/ Actually Acindar did add to the plant a third small Siemens Martin furnace identical to its two existing ones in 1964. (This was much to the chagrin of the plant's engineers's who wanted at the very least a much bigger and more modern Siemens Martin even if they could not have an electric arc furnace!). But this was the only instance of expanding plant capacity by the "conventional" means of duplicating existing production units. In every other main plant stage, the capacity of the existing installations was "stretched" and this was also done in the steelmaking section itself.

to seek to "stretch" the capacity of its existing installations at Rosario at the lowest possible investment cost. This is exactly what they did.

5.2 Capacity-stretching in USIMINAS

Our next example relates to the way in which production in USIMINAS's original plant was stretched from the level reached in 1966 of 500,000 tons of flat products per year - which corresponded to the plant's nominal capacity - to over 1,200,000 tons per year by 1972. This was done without introducing any major new equipment units, and at very low investment cost. The reader is referred back to Table 5.1 where the impressive extent of capacity-stretching achieved in USIMINAS's various equipment units can be noted. Furthermore, Chart 5.2 below traces in detail the capacity-stretching achieved in USIMINA's BOF steelshop. We now look at the circumstances in which these very notable results were achieved.

Like in the Acindar, Rosario case it must be said straightaway that a "stretching" on this scale was certainly not contemplated in the original plans for USIMINAS. What actually sparked off the succession of technical changes with which USIMINAS stretched the capacity of its plant was a deep financial crisis in the firm.

Accordingly, we shall first describe how this financial crisis arose.

Secondly, we shall describe how the "conventional" means which the directors of USIMINAS wished to use to increase their plant's output (and thence its sales and profits) so as to resolve their financias crisis were ruled out by the circumstances prevailing at the time - which then meant that the only alternative remaining was for USIMINAS to try to stretch the capacity of its existing installations at low investment cost.

To begin with, let us see how USIMINAS got into a financial crisis.

Several factors came together here. In particular:

1. The original investment required to construct the plant escalated a lot compared to forecast. This was caused by rapid Brazilian inflation in between the plans and the actual construction period, as well as the devaluation of the Brazilian cruzeiro. a/

2. In 1964, just after USIMINAS started steel production, domestic steel demand in Brazil dropped by over 20% and did not fully recover until 1968. b/

3. Coupled to the retraction in demand, USIMINAS had the problem of the near simultaneous entry into the market of the flat-products output of the other new state-promoted firm COSIPA - which accentuated excess capacity in several types of flat products. c/

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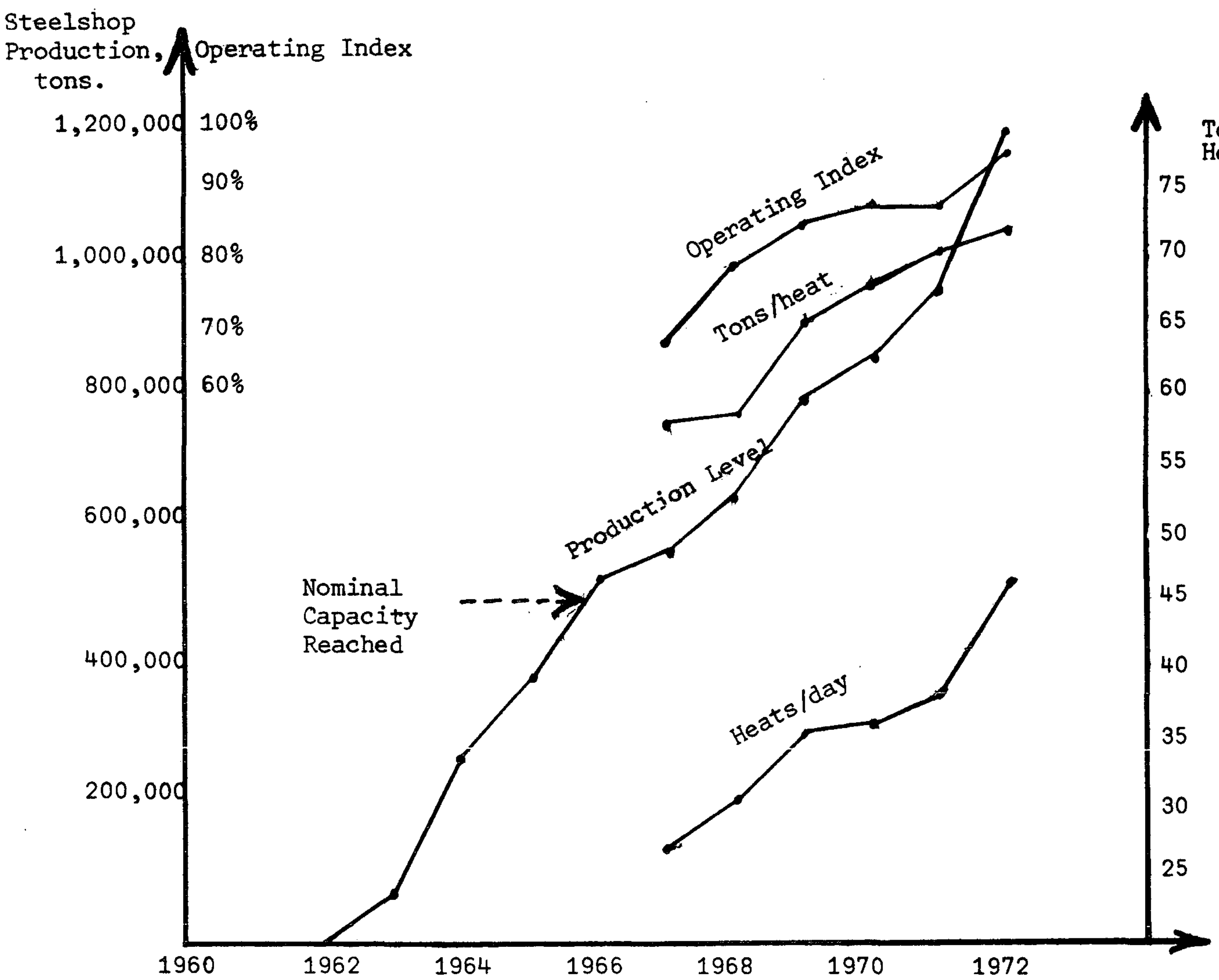
a/ USIMINAS Report, p, 47. 118, 119.

b/ Ibid. p. 68.

c/ Ibid. p. 73, 74, 76.

Chart 5.2 Capacity stretching in USIMINAS
BOF Steelshop No. 1, 1963-72



Source: Figures from USIMINAS Report, Vol. II, p. 136.

4. Price controls introduced at the beginning of 1965 kept the price of steel at an artificially low level while the cost of inputs was allowed to increase as a result of rapid general inflation. This situation was not righted by the government until 1968. a/

5. Furthermore, tariffs on imported steel products were reduced from an average 60% to 50% in 1966 and then to 40% in 1967, and on a substantial portion of flat products to as low as 15% - thus stiffening the competition from imports. b/

The net result of these five factors was that USIMINAS first built up large unplanned debts before entering production (due to the inflated initial investment cost) and then found it difficult to correct the situation upon starting up production because its sales income was lowered by a combination of low prices, low effective domestic demand and competition from COSIPA and imports.

Fortunately, this situacion was perceived by USIMINAS early on, and led to two main responses by the firm designed to improve the situation. These were (a) a great emphasis on quality production for export sales which permitted USIMINAS to export 39% of its output in 1965, 18% in 1966 and 33% in 1967, thus mitigating the domestic demand crisis; and (b) the launching by USIMINAS' directors of a strategy to greatly expand the plant's output so as both to increase sales income and reap economies of scale in investment costs and direct production costs.

Indeed, as early as the 1965, USIMINAS's directors, in their annual report reckoned that to break even, USIMINAS would need to attain a minimum production level of 1 million tons per annum. In the same year, they accordingly drew up an expansion plan to reach 1 million tons, which estimated that investments of around U.S.$ 70 millions would be needed (on top of the figure of U.S.$ 270 million which the original plant was reckoned to have cost). c/

This first expansion plan was submitted to an international financial agency in 1965 but was not approved because of the high debt-sales ratio of USIMINAS and the low prices and demand prevailing in the Brazilian market. Later on, in 1966, a more detailed project to expand up to 1 million tons and a preliminary project for 2 million tons were submitted by USIMINAS to the Consultants then doing the planning studies for the Brazilian government on the future of the national steel industry - but these projects to expand USIMINAS were not approved either.

In the event, it was only in 1967 that the government-appointed Special Advisory Group on the Steel Industry finally recommended that USIMINAS should be authorized to expand up to 1.4 million tons, a recommendation that was accepted in the 1968 National Steel Plan. This expansion was planned on

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a/ Ibid. p. 74, 75, footnote to p. 77.

b/ Ibid. p. 76.

c/ Ibid. p. 47.

the basis of substantial new investments and additions to the existing plant, e.g. additional coke and sinter plants, remodelling of the two existing blast furnaces, addition of a thir BOF converter, etc. However, although approved in 1968 the implementation of these additional investments for the expansion plan was slowed down by negotiations with the government backed Brazilian National Development Bank on how they would be financed, and these were only finally resolved in late 1969, so that the new installations only began entering into operation from late 1970 onwards, a/ and the main new equipment units only in fact entered production in 1973. b/

In summary, if we term the expansion of plant capacity by substantial additional equipment investments "conventional expansion", then what we have seen is that USIMINAS's own financial crisis coupled with the Brazilian Government's actual planning and financing decisions on the steel industry led to a situation whereby (a) USIMINA's conventional expansion plans were blocked by lack of finance between 1965 and 1969, and (b) the facilities corresponding to conventional expansion only came on-stream in 1973.

Yet USIMINAS had already in 1965 realized that it urgently needed to increase sales income and reduce production costs through doubling its original capacity and production levels, so as to reduce its high debt to sales ratio.

In other words the firm already had an urgent need in 1965 to expand production and sales, but little money to invest in making this possible.

It was in these circumstances that "capacity-stretching" on the existing plant at low investment cost became a clearly attractive option and this option was then followed up consciously between 1965 and 1972.

5.3 Capacity stretching in AHMSA

Our third example is from the record of AHMSA and refers to capacity stretching in AHMSA's Siemens Martin steelshop. Chart 5.3 shows that there has been a constant increase over the years in the production per hour from this steel shop. This has been to a large extent due to the installation of additional Siemes Martin furnaces, as is shown in the chart. Thus, the plant started with just one Siemens Martin furnace in 1944. A second and third were quickly added in 1945 and 1947. Then five additional, and larger Siemens Martin furnaces were added between 1953 and 1964.

However, a further effect can be noticed in Chart 5.3. This is the tendency for the output per hour to increase in successive years when the same number of furnaces were in use. This is particularly noticeable from 1964 onwards when all eight furnaces were working.

As we shall see, this post-1964 effect is closely related to a particular "circumstance" in the AHMSA expansion story: namely the fact that 1964 was

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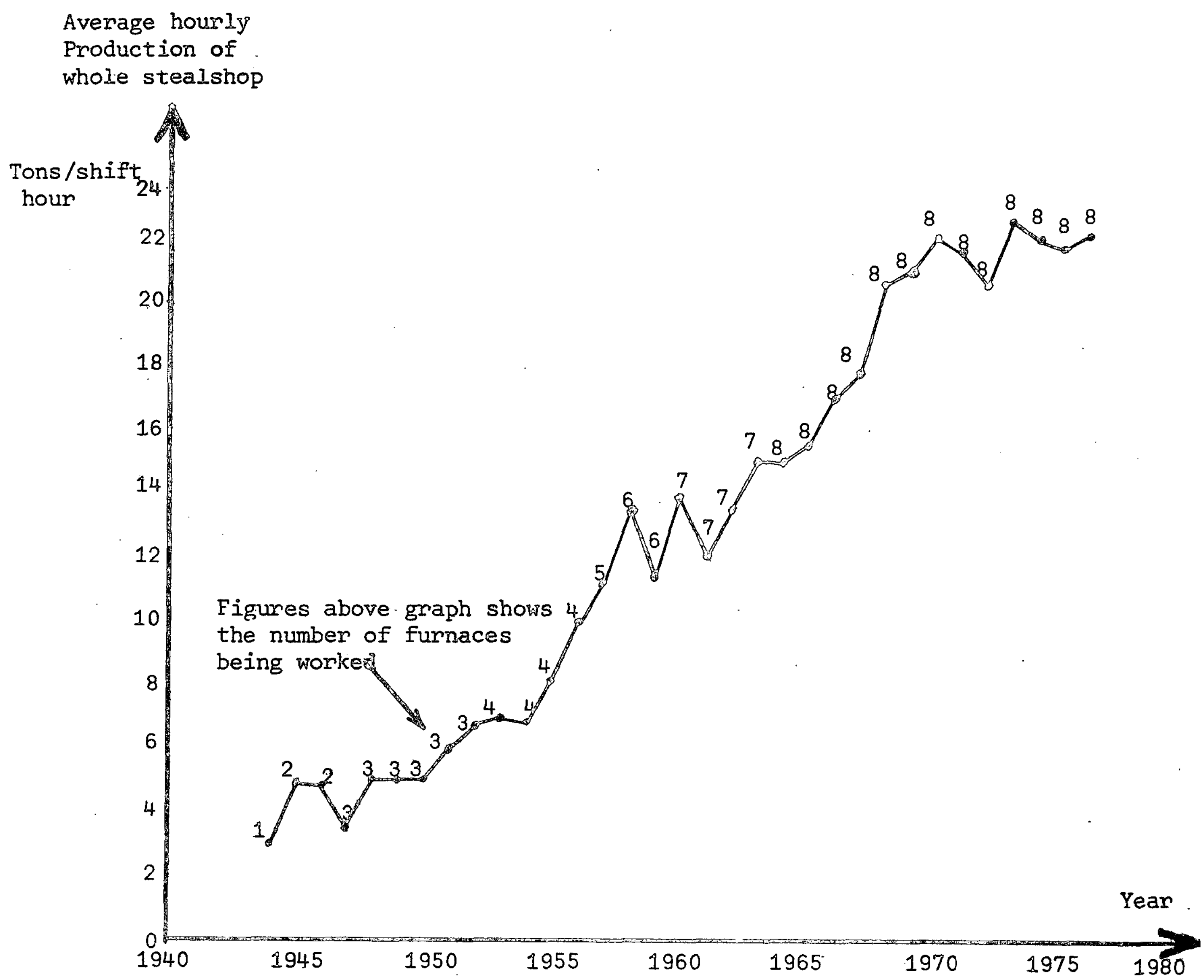
a/ USIMINAS Report. p. 120, 121.

b/ Ibid. p. 123.

Chart 5.3 Increase in the average production per hour of AHMSA's Siemens Martin steal shop 1944-1976



Source: AHMSA Report, p. 97.

the last year in which in an additional new Siemens Martin furnace was installed in AHMSA's steel shop its eight and final furnace of this type.

In the normal course of AHMSA's further expansion to meet constantly rising levels of domestic steel demand, one would have expected further new Siemens Martins to have been added during the second half of the 1960s and the early 1970s -- however this was not done because AHMSA, following world trends, decided in 1967 that the more recently developed BOF (oxygen converter) technology for making steel was more economic than Siemens Martin steelmaking, and therefore that they would instal BOF in their further capacity expansions.

As a result of this decision by AHMSA, it became apparet "that right from the planning stage for the first BOF shop the economic resources of the firm were principally directed to the future new steelshop, and the Siemens Martin shop began to get displaced so that investments in it were only directed to maintain it in operation rather than improve it". a/

This meant that - like in the Acindar and USIMINAS cases - any improvements from 1967 onwards of AHMSA's Siemens Martin steelshop were subject to a clear investment constraint (i.e. to a regime of low, or minimal new investment).

It is interesting, therefore, to note - from the AHMSA study - that this situation of being "relegated to secondary status" b/ and being "practically condemned to disappear" b/ led to a clearly competitive response from the Siemens Martin personnel, who made increased productivity the "central objective" of their steel shop, b/ and who brought about a whole series of consequent technical changes at zero or very low investment cost, whose principle objective was to reduce production costs. b/ c/

The authors of the AHMSA study are emphatic that this series of changes would not have been carried out were it not for the competition provided by the BOF shop, d/ and the challenge thus presented to the Siemens Martin shop to improve performance so as to survive, or survive longer. (Here there is a very clear parallel to the Acindar Rosario situation where plant personnel always know that their plant was under "suspended sentence of execution".

A further point - which the authors of the AHMSA study surprisingly do not make - is that in the years 1967 to 1972, when the new BOF shop was being planned and built, veri considerable "stretching" of capacity in the Siemens Martin shop took place. This can be seen in Charts 5.4 and 5.5. Thus, in

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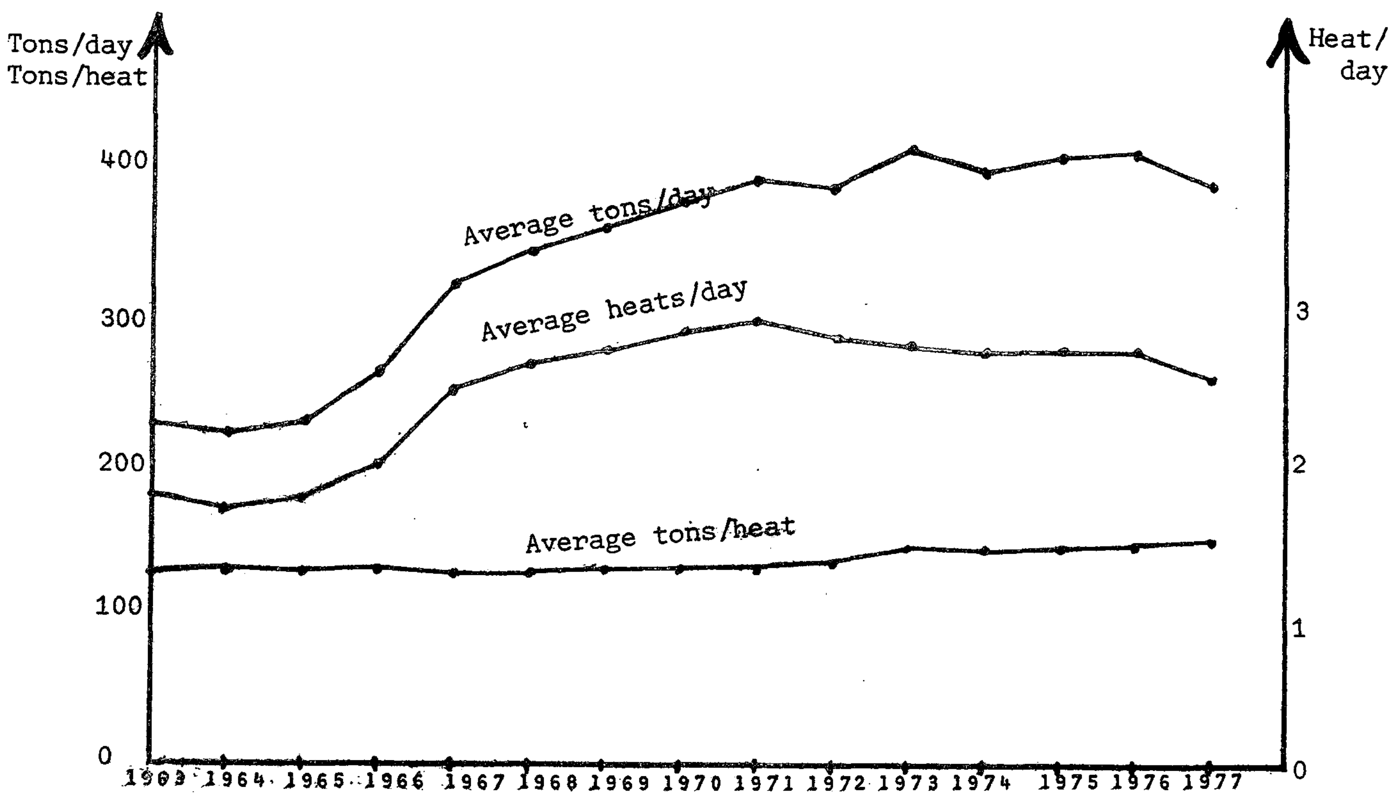
a/ AHMSA Report, p. 90, paragraph 4.

b/ Ibid, p. 88, paragraph 5.

c/ Ibid, p. 89, paragraph 1, p. 90, paragraph 5.

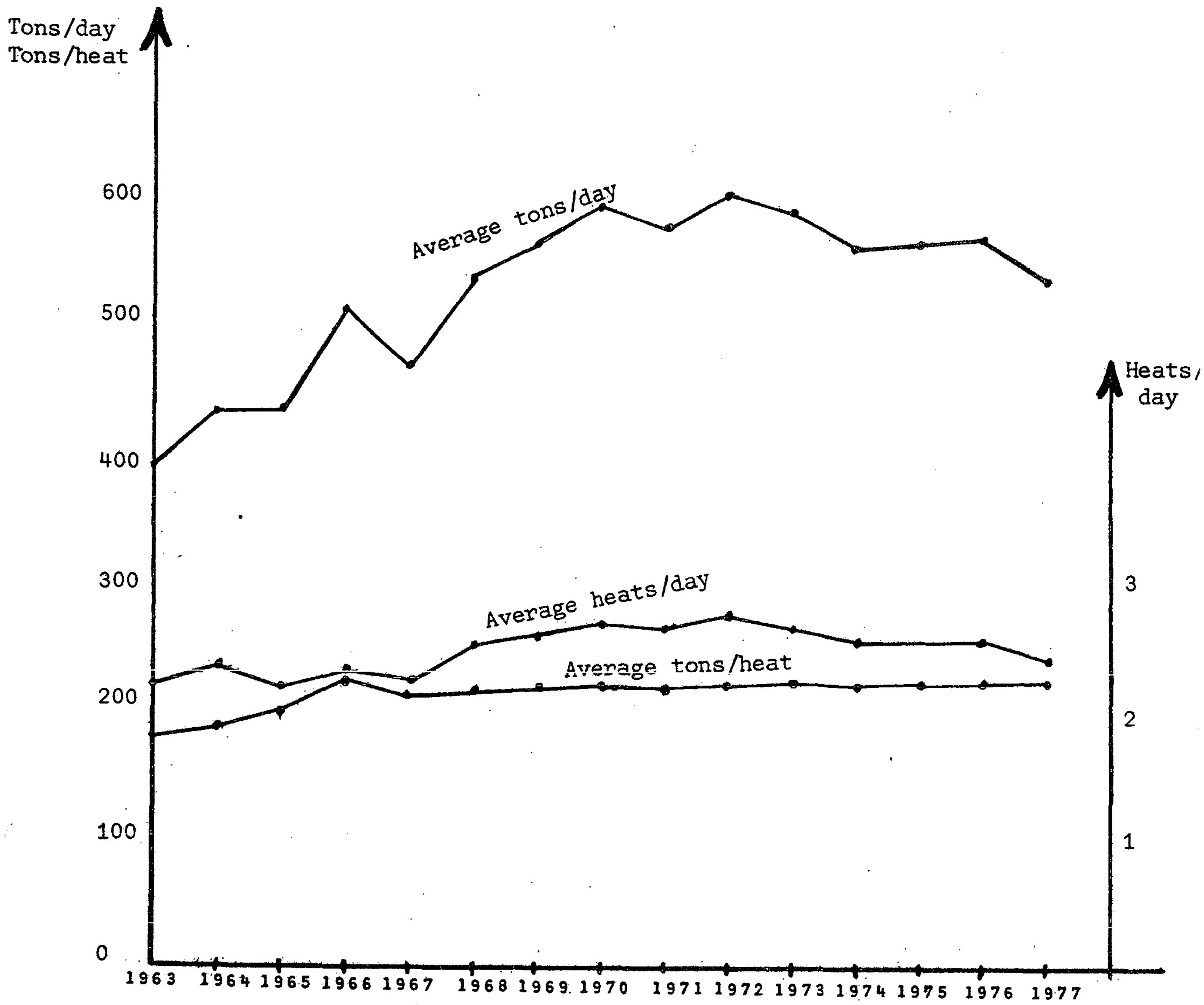
d/ Ibid, p. 91, paragraph 4.

Chart 5.4 Indicators of Capacity-Stretching in AHMSA's
3 Small Siemens-Martin furnaces 1963-77



Source: Based on figures calculated from data in AHMSA Report, pages 102 and 226.

Chart 5.5 Indicators of Capacity-Stretching in AHMSA's 5 large Siemens-Martin furnaces 1963-77



Source: Based on figures calculated from data in AHMSA Report, pages 102 and 226.

the three small Siemens Martin furnaces, perfomance was boosted from around 1.8 to nearly 3 heats per day between 1963 and 1971. In the five large Siemens Martin furnaces it was boosted from around 2.2 to near 2.8 heats per day between 1963 and 1972.

At the same time, in both the small and the large furnaces, an additional element of capacity stretching was provided by noticeably raising the average weight of steel produced in each heat.

The net effect of these two types of improvement was to stretch the production capacity of the small furnaces by approximately 81% between 1963 and 1973, and that of the large furnaces by approximately 54% between 1963 and 1972. a/

Our interpretation of this notable capacity-stretching is straight forward. It is that the years 1967 to 1972 represented a period when it was known that the BOF shop was being planned and would be coming on stream, but when, nevertheless, the expected output that would be obtained from it was obviously not yet available.

This must therefore have put a clear premium on squeezing the needed extra output to satisfy demand from the existing Siemens Martin units - yet at low investment cost because this increased output would only be needed from the Siemens Martin the relatively short time-span expected to intervene until the BOF shop would start up.

In these circumstances, of clearly "present" increased demand, but unavoidable "delays" in satisfying it on the basis of the newly-to-be-installed technology, the motivation for capacity-stretching at low investment cost seems clear enough, and bears an obvious, similarity to the situations which we have described previously for Acindar's Rosario plant and for USIMINAS.

5.4 Summary

In all three cases described above, capacity-stretching was extensively resorted to as a kind of "second-best" option when the conventional expansion options that the firm would have liked to engage in were blocked or delayed.

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a/ Furthermore these figures may well understate the true degree of capacity stretching actually achieved, because in the period 1967-72 there was also a noticeable decrease in the fraction of the load to the Siemens Martin furnaces that consisted of liquid pig iron ('hot metal') from the blast furnaces. (The fraction of hot metal charged to the small furnaces dropped from about 75% to about 50%, and in the large furnaces from about 60% to about 45%). This meant that a greater fraction of the load to the furnaces consisted of cold scrap that had first to be melted, which would, other things equal, lead to a slower working cycle and therefore to less heats per day. This was evidently more than compensated by changes in operating techniques which speeded up the overall production cycle, and produced the capacity stretching that we have observed.

The effects of these blocks and delays was that expansion could not -temporarily- be brought about in any other way than by capacity-stretching within a low-investment constraint.

Specificly it appears from the above cases that the following three kinds of circumstances provoked the blocks and delays to conventional expansion which in turn made capacity-stretching necessary.

i. Rather long normal timelags inherent in the technological aspects of planning, designing, procuring, constructing, and starting-up whole a new plant stages or major sections thereof. (i.e. in "conventional" expansion).

ii. Expected and unavoidable political and bureaucratic delays in the process of securing official permission to undertake major "conventional" plant expansions, and in securing available government promotional incentives and/or financial guarantees. Plus the incidence of "unexpected" political and bureaucratic obstacles which lengthened the gestation period of the expansion project concerned and thus further delayed the date on which the desired increased output from the new plant could be expected to be available.

iii. Investment constraints produced by financial crises in the firm - or by management's decision to concentrate most of its available resources on rival technologies or other parts of its activities.

6. EXISTENCE OF MAY OTHER INCENTIVES TO CAPACITY STRETCHING

In the previous section we emphasized the major incentive to capacity-stretching that arose when conventional output expansion was blocked or delayed because of external factors, investment constraints, or inherently long delays in the gestation period of the major capital investments required for conventional expansion.

However, the pervasiveness of capacity-stretching in the steelplants strongly suggests that incentives to it exist in a wider range of situations than merely those when it is a "second-best" option to conventional expansion plans.

Indeed it appears that pervasiveness is in large measure due to the sheer variety of different incentives that were observed in the case studies to have motivated capacity stretching projects. Without attempting to be systematic or comprehensive, the following list of icentives, all drawn from the case-studies, will be, illustrative:

i. Indivisibilities in steelplant equipment, which meant that small increments in demand could not economically be met by adding whole new units.

ii. Disequilibrium inducements to stretch capacity caused by bottlenecks and/or imbalances in the capacities of different plant stages.

iii. Accumaltion of experience due to learning-by-doing in the daily operation of plants. This leads to the improvement of operational routines and the spotting of many minor design-defects and potential design-improvements which could raise capacity at low investment cost.

iv. Temporary demand-peaks, which lead to efforts to raise the capacity of the existing plant, but which would not justify investing in extra new capacity.

v. Stimulus provided by visits to other plants where capacity-stretching techniques are seen at work.

vi. Stimulus provided by the wide diffusion in the trade lietrature of capacity-stretching innovations tried out successfully in other steel plants.

vii. Stimulus provided through technical assistance contracts with a foreign steel producer or engineering firm that provide a channel for recommending innovations, including ones that stretch capacity.

viii. The "perfomance'improving'instincts" of plant engineers keen to get more out of their existing equipment, which leads them to work-up and recommend capacity stretching projects.

ix. The need for capacity-stretching as a pre-condition for securing cost-reduction achievable through greater output levels.

x. The "spin-off" incentive in terms of capacity-stretching obtained "free" as a result of technical changes carried out primarily with other objectives in mind (e.g. to reduce production cost or improve product quality.

This long list of different observed incentives for capacity-stretching - in conjunction with the incentive discussed in the previous section - goes some way towards explaining the "pervasiveness" of capacity-stretching efforts that we observed in these plants; for, clearly, a very large variety of "trigger events", both external to the plant and internal to it, can - and did - activate one or more of the capacity-stretching incentives mentioned. a/

Furthermore the disequilibrium inducement to stretch capacity caused by bottlenecks or imablances in different plant stages seems to act as a "multiplier" of the number of capacity-stretching projects that steelplants engage in. This happens because almost any capacity-stretching initiative in one particular plant stage (whether-originally inspired by external or internal stimuli) is likely to stimulate or induce a further stream of secondary capacity-stretching adjustments to correct the new bottlenecks and imbalances that then arise. b/

So both the variety of different external and internal incentives to capacity-stretching and this "multiplier effect" help explain why capacity-stretching projects were so "pervasive" in our plants, and also why their cumulative impact was so considerable.

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a/ Some examples of external "trigger events" which induced capacity-stretching in our plants included: a) severe unplanned shortfalls in competing supplies or in imports due to production or balance-of-payment problems - which led to temporary demand peaks for steel end products or intermediates, b) currency devaluations, rapid inflation, and government price controls, which enroded steel firm profitability and led to investment constraints ruling out conventional expansion, c) unusual or unexpected demand peaks caused by nes government-subsidised public works programmes or by shortage of steel products on the world market, d) changes of plans by the government which blocked or delayed conventional expansions, e) autonomous demand increases which exceeded production capacity in different product lines.

b/ "When a single innovation is adopted within an existing system of production, it sets up pressures and open opportunities for successive 'ripples' of change in other parts of the system. Such pressures may be manifest in successive bottlenecks at different stages of production as managemente strives to realize the full potential of an innovation. Alternatively, the adoption of an innovation at one stage of the process may impose more severe requirements for quality and uniformity at earlier stages. As a third, and more favourable possibility, the initial innovation may create or unblock a variety of possibilities for profitable change at other points in the production process...". William S. Pierce, The Ripple Effects of Technological Innovation, The Case of Iron Ore Pelletizing, Omega, Vol. 2, No. 1, 1974.

A more systematic approach to understanding pervasiveness, which relates it to some technological characteristics of the steel industry, is presented later on in Section 9.

7. METHODS USED TO STRETCH CAPACITY

7.1 Existence of a "generic" set of capacity-stretching methods:

A further finding that emerges from comparing the steelplant case-studies is the great similarity that can be detected in the methods used to strech capacity in the different plants.

This similarity is specially notable, as would be expected, between technologically similar units in the different plants - e.g. as between the Siemens Martin funaces of Acindar (Rosario) and the Siemens Martin furnaces of AHMSA, or the blast furnaces of USIMINAS and the blast furnaces of AHMSA, or between the various rolling mills in the different plants.

But even more significant is that one can clearly detect a "generic" similarity between the capacity-stretching methods used across all these different technologies. In other words what appears to be underlying all the methods of capacity stretching observed is a central cluster of generic techniques - which presumably could also be applied to other metallurgical and process plants beyond the confines of the steel industry.

To make this clear, we shall now list these "generic" capacity stretching techniques, and then comment briefly on them.

The generic techniques that were used to stretch capacity in our steel-plants seem to have been:

1. Improving the characteristics, control, preparation classification and standardization of the raw material "charge" to the process in question.	LEADS TO HIGHER OUTPUT YIELDS PER TON OF INPUT AND LESS PROCESSING DIFFICULTIES WHICH CAUSE HALTS IN PRODUCTION.
2. Increasing the usable volume of the containing vessels, in those cases where chemical reactions are involved.	INCREASES BATCH SIZE AND THROUGHPUT PER VESSEL PER DAY.
3. Varying operational and equipment parameters so as to speed up cycle-times in each component physical, mechanical or chemical stage of the process.	INCREASES NUMBER OF 'CYCLES' AND HENCE THROUGHPUT PER DAY.
4. Speeding up materials handling and transport between stages via improved mechanization and better layout.	INCREASES NUMBER OF 'CYCLES' AND HENCE THROUGHPUT PER DAY.
5. More precise and rapid process-control and quality control, via improved and more intensive monitoring of process variables, and more rapid control-response-times.	LEADS TO 1. HIGHER PRODUCT YIELDS PER TON OF INPUT. 2. LOWER PRODUCT REJECTION RATES.

6. Boosting the availability of processing units by incorporating more durable and reliable materials, components and accesories in those parts of the units most subject to wear out, and by developing maintenance and preventive maintenance techniques which reduce the "down-time" of units needed for their cleaning, maintenance and repair.	INCREASES NUMBER OF ACTUAL PROCESSING HOURS/DAY PER YEAR, THUS BOOSTING ANNUAL CAPACITY.
7. Redesigning, or upgrading the numbers, capacity and reliability of auxiliary equipment units so as to match or permit faster cycle times in the main units.	FREQUENTLY A CONDITION FOR SECURING THE CAPACITY IMPROVEMENTS OF TYPES 1 to 6.
8. Building up production experience which leads to improvements in labour operating efficiency.	CONTRIBUTES TO FASTER CYCLE TIMES FASTER AND BETTER QUALITY CONTROL AND MORE RAPID MAINTENANCE ACTIVITIES.

Abundant examples of all these generic capacity-stretching techniques can be noted in the case-studies.

To illustrate, let us take just one of the mehtods of capacity stretching mentioned above - that of speeding up processing cycle-times. This theme appears again and again in the different equipment units in the different plants. Thus, in USIMINAS' and AHMSA's blast furnaces, cycle-timeswere raised by such steps as increasing blast pressures and temperatures, injecting oxygen into the furnaces and more uniform operation obtained by closer process control. In Acindar's and AHMSA's Siemens Martin steelshops faster cycles were achieved by speeding up scrap-loading, by using more hot metal in the charge, by the use of higher flame temperatures and oxygen injection to speed up the refining reactions. In rolling mills in all the plants, faster operation and cycle times were obtained by rewinding motors to increase rolling speeds, superior synchronization to lower "dead times" in between successive slabs or bars being rolled, more precise roll-guides and tension guides to avoid production halts and "cobbles" etc. All these methods are also used in steelplants all over the world.

But, is this result in fact surprising? Perhaps not, if one realizes that the idea of speeding up process cycles, which in turn increases capacity, is a quite natural idea for steelplant engineers and technicians. Natural for engineers, too are such goals as minimizing production halts through better maintenance, and trying to acquire greater control ver process variables, and ideed all the other goals in our list as well.

Thus, form an engineering viewpoint there is nothing actually surprising about our finding that capacity stretching projects in the categories mentioned above were found in all our plants. These are just the kind of things that engineers are trained to do.

Nevertheless, a caveat is in order. Although the generic principles of how to stretch the capacity of steelplant units are easy enough to state, and can be seen embodied in many examples in our case-studies, this does not mean they were easy to implement. There are two main reasons for this:

1. The inherent complexity of process variables and lack of precise theoretical models to describe what is going on in blast furnaces, steel furnaces, and rolling operations mean that a great deal of empirical knowledge and experience needs to be gained so as to control and improve them successfully.

2. The actual detailed process conditions that characterize each steelplant are highly idiosyncratic because of innumerable variations between plants in terms of different equipment and raw material characteristics distinct grades of steel being processed, different size ranges of intermediate products, variations in operating practice and end-product specifications etc. - which means that simple copying of techniques used in other plants is usually impossible.

As a result, capacity-stretching projects in our plants nearly always required a considerable input of in-plant know-how, design and experiment in addition to knowledge about those specific operational, equipment or maintenance innovations which might be suitable for the task. Also, of course, management agreement was required to invest the sums needed for modifying equipment, acquiring new auxiliary units, testing new operational methods etc.

This means that, although the generic capacity-stretching technics used were common across all our plants, the extent to which capacity-stretching potential was actually exploited in each plant was clearly dependent on 1) technical capacity of the firm, 2) its access to information about possible capacity-stretching innovations that could be introduced, and 3) the structure of economic incentives and of expected costs surrounding individual capacity-stretching projects and the way these were evaluated by the firm bearing in mind its investment policies, investment constraints and alternative investment projects.

The impact of these three sets of variables (different in each plant) means that a simple comparison of our plants on the basis of their adoption or non-adoption of certain kinds of capacity-stretching methods would tell us next to nothing about the comparative "efficiency" of the firms in exploiting the capacity-stretching potential of their plants.

Nevertheless the case-studies <u>do</u> provide some interesting "pointers" concerning some of the more efficient and systematic ways of exploiting capacity-stretching potential. This is the subject of the next section.

7.2 Pointers towards the systematic exploitation of stretching potential:

Although a "direct" comparison of capacity-stetching efficiency in the three plants cannot be made, the case-studies illustrate two broadly different approaches to capacity-stretching, and also point towards an "evolution" from one approach to the other in each plant over time.

These two broad approaches can be characterized as

1. The "ad-hoc, defensive" approach to introducing capacity-stetching innovations.

2. The "systematic, offensive" approach to introducing capacity-stretching innovations.

To see what is meant by these two labels, we shall give some examples from the case-studies.

First of all consider the case of visits to other steelplants. In all the case-studies such visits were reported as important sources of ideas both for capacity-stretching and other kinds of technical changes. However, one gathers from the interviews carried out, and the reports themselves, that the visits to other plants were not usually systematically programmed but took place under the influence of an essentially random, hazard, and fortuitous set of factors - e.g. the impulses of senior managers to see other plants, the opportunities seized by younger staff sent abroad for training to look at plants in their host country etc. Indeed in the AHMSA Report it is clearly stated that "there did not exist an explicit and periodic programme of visits to exchange information about problems and solutions". a/

An interesting contrast to this essentially "ad-hoc" approach to gaining information by visiting other plants is provided by an experience related in the USIMINAS Report. As from 1967 USIMINAS wanted to stretch the capacity of its steelshop from 600,000 to 700,000 tons per year, so what it did was to commission a study "of how its converters compared with those of 16 U.S. plants in terms of characteristics and production" b/, - and this study showed that the increased capacity could be obtained with only minor specific changes in operating practice plus stengthening of some auxiliari units. What this example illustrates is the use of a systematic and precise scanning approach to the information available from other plants - as opposed to the essentially "random" approach implied by occasional visits. Interestingly, amongst our plants, USIMINAS is also the one that most systematically scans the world steel literatura c/, and also the one that appears to make the most systematic and creative use of external technical assistance. In this regard, it is not surprising that one of the most important innovations introduced by USIMINAS to stretch the capacity of its original steel-shop was the "three-holed oxygen lance" that was suggested to the company by Nippon Steel with whom USIMINAS

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a/ AHMSA Report, p. 27.

b/ USIMINAS Report, p. 170.

c/ USIMINAS's Center of Technical Information "has the best library on steel in the country and maintains permanent contact with the main information organs in the country and in the world in order to collect information of interest... The Research Center has its own technical library staffed with 19 persons with over 5,000 books and its own subscription to 329 relevant technical journals and magazines apart from those in the main library". USIMINAS Report, p. 216.

had a ten-year technical assistance contract. a/ External technical assistance has also been important in AHMSA and in the Acevedo and Marathon plants of Acindar.

A quite different illustration of the differences between an "ad-hoc" and a "systematic" approach can be gathered from the record of capacity-stretching in Acindar's Rosario plant. In Acindar, Rosario - in contrast to USIMINAS - the sources of technical change have been almost exclusively internal to the plant. Rather than scanning the technological horizons, Rosario staff have always been concerned with "doing their own thing" and improving their technology with small resources and a lot of in-house ingenuity. In the rolling mills section, virtually all technical changes during many years were introduces as responses to particular machinery problems, breakdowns, and processing difficulties that cropped up during production and which interrupted smooth funcioning - i.e. fundamentally an "ad-hoc" troubleshooting approach. b/

However, there was a further development, for in the period 1969 - 71 the men who had spent many years attending to the Rosario mills with this trouble-shooting" approach, had the opportunity to introduce substantial design modifications of their own into the plant's billet mill and its bar & section mill. This led to two low-cost but highly effective projects - entirely designed in house - which both had an extremely notable capacity-stretching impact. Analysis of these two projects shows that they were based on the long-experience and detailed familiarity of their designers with virtually every facet of these mills, their operation, their design probmes, faults and possibilities. This enabled an extremaly precise, detailed and compehensive combination of modifications to be introduced in both cases which systematically exploited the available equipment, motor-horsepower, and space-available to the maximum extent at minimum extra investment cost. c/

The critical point in this example is the shift from an "ad-hoc" trouble-shooting approach to a "systematic approach" which is made possible by the growth of familiarity with the process to be improved - this growth itself occurring due to the experience acquired in by plant staff operating the process and coping with the difficulties involved.

This shift from an "ad-hoc" to a systematic approach based on growing process familiarity was clearly observed in all our steel-plants. For example, in the AHMSA Report, we find the following passage which describes the sequence

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a/ USIMINAS Report, p. 172.

b/ Indeed as experience built up, this came to be rationalized as a specific design philosophy, stated as follows: "To go along, eliminating passes, redesigning rolls so as to minimize problems, to roll with greater cross section wherever possible, to try to minimize production halts and nuisances, and if possible to withdraw men because it is pretty unpleasant type of work involving risks of getting burnt; to go along making adjustments in the elements or accesories of the mill which bring you problems". Source: Acindar Report (Draft Thesis Version), p. 9.25.

c/ Both projects are described in detail in the Acindar Report (Draft Thesis Version) pp. 9.34 to 9.37.

of events after 1971 when the firm acquired a great deal of sophisticated "best-practice" new technology (including BOF technology) for the first time:

> "The degree of foreign technological dependence increases during the guarntee period because during this time any operational problem with the technology must be directly resolved by the suppliers. Once this period is over, a period of learning is necessary so as to get to know deeply about the functioning of the process and the equipment, during which external assitance is sought sporadically. Finally, starting from this knowledge-base, a processo of trial and error is begun (without having a very solid theoretical basis ex-ante, but regularly generating one ex-post) in which the aim is to incrementally improve and optimize the operational routines laid down by the foreign equipment suppliers." a/

In other words, it requires a considerable period of prior familiarization and "trial and error", before plant staff develop a good understanding of the interplays and subtleties of the complex set of equipment and process parameters and variables that they control. So it is only to be expected that early capacity-stretching efforts will be more ad-hoc than systematic, and that these early efforts will usually arise in the course of trying to keep the process going when it is faced with specific operational difficulties, rather than through unforced experimentation on potential improvements.

This difference between "early" an "later" capacity-stretching is also borne out strongly by USIMINAS's experience. For example, in the sinter section

> "the initial effort was devoted to learning about the basic process itself, particularly the influence of various physical and chemical qualities of the process. As these were learned, greater efforts were directed at controlling the basic characteristics of the raw materials. In large part this involved reaction to the variations in these qualities in the raw materials received. (Reactions to external fluctuations). Third, as more experience was gained, better methods were developed, including not only changes in raw materials used, their handling, preparation, weighing etc., but also of the process itself. To do this it was necessary to not only modify or add various pieces of equipment but to develop new organizational methods involving training, learning and studying various aspects of the process. b/

So we see that USIMINAS's experience confirmas AHMSA's and Acindar's in showing why one would expect to find later capacity-stretching efforts are characterized by a more comprenhensive, sophisticated - and "theory-intensive" approach tahn earlier ones.

A further important characteristic of "later" capacity-stretching efforts was also detected in the case-studies. This has to do with the problem that

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a/ AHMSA Report, p. 24.

b/ USIMINAS Report, p

as the more "obvious" capacity-stretching steps are taken, any further stretching will often depend on extending efforts to hitherto neglected components and aspects of the process.

For example a "saturation" of this kind was detected in USIMINA's steelshop, where if one reads through the list of measures being considered by the company for its "fourth wave" of capacity-stretching in this steelshop, what is striking is the cumulative number and range of the efforts being considered and the number of components identified for improvement. (These included changed operating practices in charging the converters, redimensioned ingot moulds, special refractory bricks for scrap and steel run-sites, new systems of inventories of spares, increased oxygen injection, holding extra pig iron reserves to insure against production halts, and improvements in calcination.) a/ What is reflected here is that USIMINAS apparantly wanted "no stone left unturned" in their efforts to stretch capacity further and further towards inherent design limits, and therefore were prepared to systematically try to improve virtually every component of the process - a task which evidently required extensive prior familiarity with the process concerned. A similarly "comprenhensive" approach to capacity-stretching - via revising literally every possible component - was also a feature of the two projects in the Acindar Rosario rolling mills mentioned earlier.

A final point worth making shilst dealing with the theme of "systematic" capacity-stretching is that neither in Acindar, nor in USIMINAS was there any clear idea beforehand of just now much they would in fact be able to strech capacity. So far as Acindar is concerned, back in the 1950s no-one conceived it possible, or thought of planning to stretch the Rosario plant's capacity to the extent that was finally achieved. The actual cumulative stretching finally achieved was the unplanned outcome of a long series of efforts carried out successively given the reiterative blocking of conventional options.

As for USIMINAS, as late as 1969 its Annual Report spoke of the achieved steel production level of 790,000 tons as the "maximum probable production" that could be obtained with its existing installations - and then went on in succeeding years to stretch this level up to nearly 1,200,000 tons. b/

This suggests that both Acindar and USIMINAS (and quite probabley AHMSA too) understimated the terrific possibilities that actually existed for capacity-stretching. That they in fact achieved so much seems greatly due to adverse historical circumstances which made it economically urgent for them to strech their plants to a high degree. In other words it seems that "historical jolts" (or sets of jolts) helped these firms to wake up to the full-potential for capacity-stretching in their plants. Without these jolts (which involved mainly the blocks and delays in conventional expansion plans) it is doubtful if they would have been so systematic or successful.

This completes our survey of "ad-hoc" versus "systematic" methods of introducing capacity-stretching technical changes. Our survey has not been comprenhensive - for space reasons - and, in particular, we have not mentioned

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a/ USIMINAS Report, pp. 172-3.

b/ Ibid. p. 127

several important organizational steps which our firms took in order to reinforce their internal capacity to identify and implement capacity-stretching and other changes (e.g. the setting up of a "standard-cost" system, a/ and the setting up or reinforcing of several technical departments within the plants). However, enough has been said to show that our plants were able to develop a number of systematic approaches to capacity-stretching. These ranged from the systematic scanning and exploitation of information from other plants and the use of external technical assistance, through to the executing of comprehensive process modifications based on plant staff's mastery of process kno-how that they acquired through experience.

So in addition to demonstrating the existence of several "generic" capacity stretching techniques common to all the plants the case-studies also demostrate some ways in which the firms were able to exploit these techniques in a systematic way.

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a/ "Such capacity stretching (in the first 10 years of USIMINAS) was possible thanks to the implementation of a standard cost system with an elaborate organizational infrastructure to study its existing equipment, compare it to the best world perfomance, and then try to reach the same or higher levels." USIMINAS Report, p. 263; for details of the implementation of the standard cost-system see USIMINAS Report, pp. 211-213.

8. SUMMARY OF THE EMPIRICAL FINDINGS

In the previous pages - Sections 3 to 7 - we have sought to describe salient features of "capacity-stretching" observed in the steel plant case-studies.

The main points which emerged were:

1. The great quantitative extent of capacity stretching.

2. The fact that its implementation at low investment cost was to a significant extent fuelled by the Blocking or delaying of conventional output expansion plans.

3. There were also many other kinds of incentives to capacity-stretching, which together with the "multiplier effect" of the bottleneck-imbalance incentive, help account for the "pervasiveness" of capacity-stretching projects that we noted in the plants.

4. Capacity-stretching was often the priority objective involved in carrying out technical changes, and cannot be considered as always a subsidiary objective realted to cost-reduction; it has legitimate status as an independent category of technical change, though its complementarity to cost-reduction certainly deserves exploration.

5. There appears to exist a "generic" set of methods for stretching capacity, whose use was common across all the plants and technologies within the plants; this is intelligible from an engineering viewpoint; however process-complexities and marked plant idiosyncracies mean that it was not a simple matter to apply these generic methods because straightforward copying of techniques used in other plants is not viable in this industry.

6. Both "ad-hoc" and more "systematic" approaches to stretching capacity were detected in the study - the latter being closely related to gaining familiarity and knowledge about process variables and how to control them; also some systematic ways of exploiting information from other plants and from external technical assistance were noted; finally it was observed that at least two of our plants had initially greatly underestimated the extent of capacity -stretching that they would be able to achieve.

Although these above results are drawn from studies of just three plants, we believe that the phenomenon they describe - i.e. capacity-stretching - is a widespread one in steel-plants. In fact we shall argue in section 9 below that it arises mainly because of inherent features of steel technoloy, common to all plants in the industry.

For economists interested in firm technological behaviour it then becomes a challenge to incorporate "capacity-stretching" technical change into a model of how entrepreneurs are supposed to "adjust" their plants to changing market circumstances and technology. It also becomes interesting to see how "capacity-stretching" technical changes relate to the better known category of "cost-reducing" ones. These two matters are taken up in Sections 10 and 11 below. Section 12 provides a model which explores some of the variables affecting the choice of conventional expansion versus capacity-stretching expansion in meeting demand increases. Finally, Section 13 sums up the Conclusions reached in this study.

II INTERPRETATION AND MODELS

9. AN INTERPRETATION OF WHY CAPACITY-STRETCHING IS PERVASIVE

The sheer extent and pervasiveness of capacity-stretching which we observed in all the case-studies suggests they are a consequence of some inherent technological features of the steel industry.

If this is correct, then we can expect the phenomenon of capacity stretching to be of general incidence in all well-run steelplants serving growing markets, and not just an isolated phenomenon confined to the observed Latin American plants.

Also, if we can pinpoint the technological determinants of capacity-stretching, this will help in developing an adequate theory of it.

We believe that the following four technological features of steelplants are mainly responsible for the pervasiveness: i) very large capital requirements; ii) great complexity of process; iii) multi-stage, sequential nature of process; and iv) economies of scale leading to major indivisibilities in equipment units in several process stages.

The way these features encourage capacity-stretching is set out in Diagram 1 overleaf.

The diagram shows how these features of steelplants lead to capacity-stretching due to four different sets of factors:

1. Long "adjustment delays" in conventional expansion which encourage capacity stretching as an alternative, at least temporarily.

2. The prevalence of imbalances and bottlenecks in steel-plants (due to both the multi-stage character of the industry and to major indivisibilities in equipment units)

   - which signals clearly to engineers where incremental capacities are needed.

3. The fact that "learning-by-doing" with complex steel process often leads to rated capacities being gradually exceeded as firms gain experience.

4. The fact that conventional capital-intensive expansion - even in the basence of adjustment delays - takes place at discrete intervals of time.

We shall now discuss each of these four sets of factors in more detail, pointing out their implications for capacity-stretching. Finally, we shall briefly mention several other factors that also encourage capacity stretching.

9.1 Long "adjustment delays" in conventional expansion.

Overall complexity of steelplant technology leads to sophisticated and time-consuming requirements in the planning, designing, procuring, constructing and starting up of major "conventional" expansions of steel capacity - (i.e. entirely new plants, or major capital-intensive expansions of existing plants).

This leads, necessarily, to a long "gestation period" for conventional expansions, starging from the moment the investment is firmly decided upon and approved by the necessary authorities. In fact, economists recognise the existence, within the gestation period, of a "construction period" and then a "start-up" period which goes from the beginning of production through to the achievement of production at rated capacity levels. a/ In the steel industry, the overall gestation period (i.e. construction plus start-up) can last from 2 to 7 or more years.

However, for planning purposes in the steel industry it is indispensable to also recognise an additional previous delay period (which economists have termed the "pre-investment" period) during which a) the feasibility report for the proposed conventional expansion is prepared, b) government agreement to the project itself, and to providing the firm with promotional incentives and other financial help, is sought, and c) loans to financie the project are negotiated with national and international banks, and from the equipment suppliers. The need for all three of these steps is directly related to the hughe capital requirements of the industry, b/ and the long amortization periods involved, which mean that firms' internal fund sources are usually grossly insufficient for investing on the required scale.

This additional "pre-investment" period, can also be long, and is quite regularly measured in years, particularly when the home government's project planning and approval procedures for its steel industry have become subject to paralysing policital conflicts c/, or, to put it more politely, "administrative rigidities".

Our term "adjustment delay" is explicitly intendend to describe the overall delay involved in conventional expansion projects in the steel industry. This

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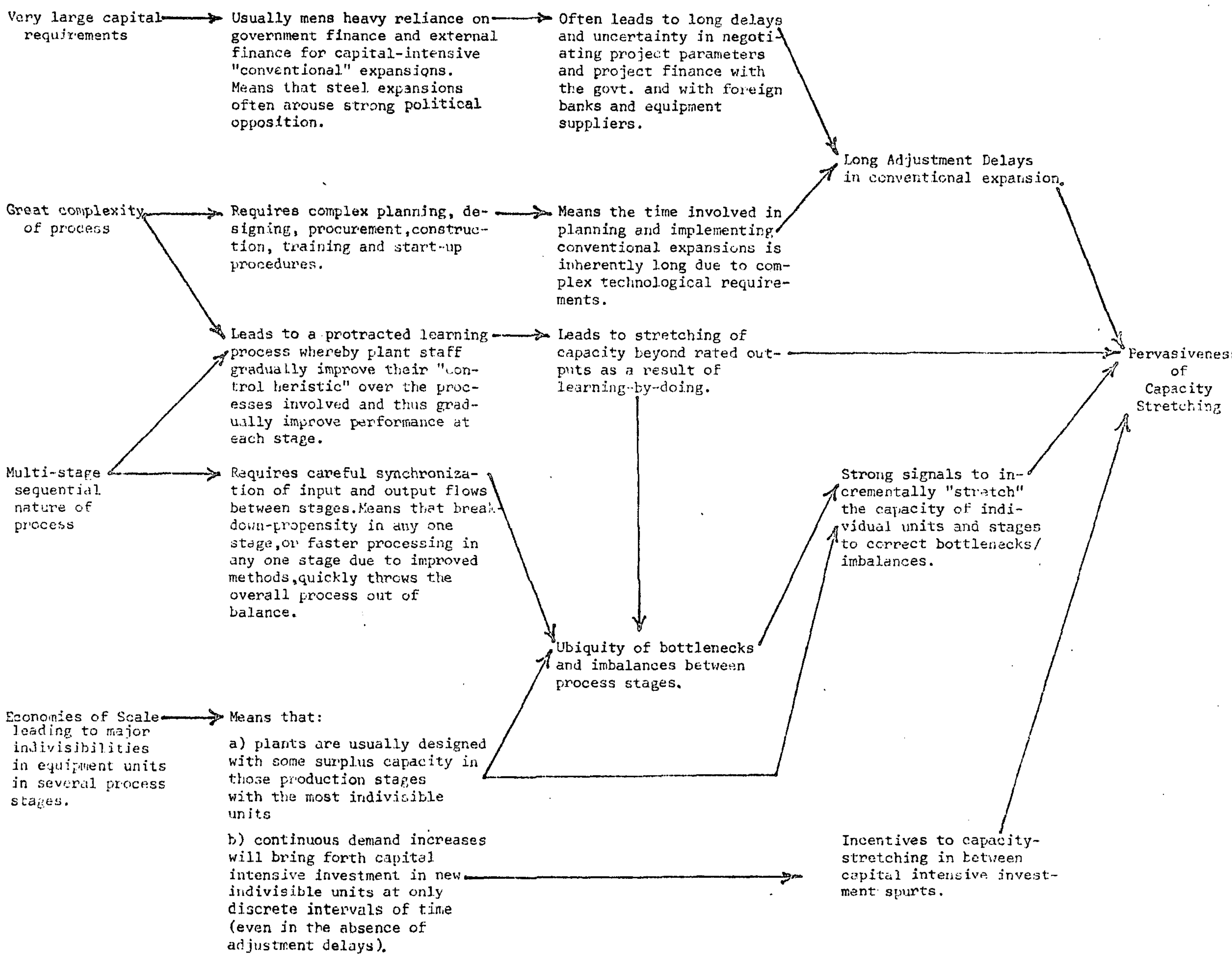
a/ Some tuning of equipment, and production from parts of plants, may often begin before the construction period has ended. Eckhaus (1973) 1/ refers to the period starting from tuning of equipment up until full rated plant capacity is achieved as the "maturation perio". However, the better known term "start-up period", see Baloff (1963) 2/ - is preferable.

b/ For new capacity, investments of hundres of millions of dollars would be normal for semi-integrated plants, and thousands of millions of dollars for integrated plants (roughly $ 1,000 million per million tons of annual ingot capacity).

c/ This has certainly been the case for many years in the Argentine steel industry. See Maxwell (1976) 3/ It has also been a major factor at times in the British and Indian steel industries, and is common in many other countries as well - the major source of political conflict often being the priority of public sector vs. private sector firms.

Diagram 9.1 Explanation of why Capacity Stretching is Pervasive in Steelplants



obviously includes both the "pre-investment" period and the "gestation" period.

The sheer length of the adjustment period - even for the most efficiently and rapidly financed and excecuted conventional expansions - is such as to rule out conventional expansion as a "short run" response available to a firm for varying its output in response to market conditions. Conventional expansion is, inherently, a "long-run" measure.

This explains why - if a firm is interested in increasing its output in the short to medium run, and finds itself unable to do so because of having reached bottlenecks in one (or more) stages of its existing plant - then "capacity-stretching" can become an economically attractive response.

9.2 The prevalence of imbalance and bottlenecks in steelplants.

A further powerful incentive to capacity-stretching is that imbalances and bottlenecs are extremely prevalent and frequent in steelplants. This has to do with the "multi-stage sequential character" of steelmaking which means that careful synchronization of input and output flows between stages is required, so that bottlenecs in one or more stages may restrict a plant's overall production capacity shilst unused surplus capacity can exist in the other stages. We shall now explain why bottlenecs and imbalances are in fact so prevalent, and why they often lead to capacity streching. a/

A first major reason has to do with the marked indivisibilities that characterize steelplant equipment units in several main processes b/. The effect

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a/ In a multistage industry integrated plants command some advantages over semintegrated plants due to the absence of, or imperfections in markets for intermediate products. In the case of steel, for physical reasons, there are no markets for hot metal, either hot pig iron or hot steel, which is the intermediate output/input of some of the stages. An integrated producer uses hot pig iron directly; however if a semi-integrated producer wanted to use liquid pig iron as an input, he would have to buy cold pig iron and then melt it in order to proceed with the process. In addition we encounter other reasons which generate imperfections in the markets for intermediate outputs and conrresponding advantages of integrated over semi-integrated plants: for example the periodic difficulty (or impossiblity) of obtaining large supplies of intermediates at short notice, costs of transportation and other barriers to trade, and the difficulties sometimes encountered in obtaining the exact qualities of intermediate goods which can match the requirements of the other sectors downstream in the process (e.g., steel grades for rolling specific products).
However there is another side to the coin - which is that the integrated producer has more stages in which a production problem can give rise to a bottleneck which holds up production in the rest of the plant.

b/ These indivisibilities are associated with economies of scale in capital equipment costs per ton of capacity and in operating costs per ton of output. For example, in modern large integrated plants the average output per unit of equipment such as blast furnaces, oxygen converters and strip mills can be over 2 million tons per individual unit per year. The Japanese have built blast furnaces with outputs of over 4 million tons per year.

is that incremental capacities in these stages cannot economically be created by adding whole new units. As a result it is normal for the most "indivisible" units to be deliberately "oversized" when plants are designed, a/ and - in consequence - underutilized at the initial capacity for which the plant is constructed. Thus plants often start out life unbalanced. Then, when output has to be built up in incremental steps beyond initial capacity, further capacity can be progressively added in the more divisible stages so as to match the surplus capacity available in the oversized units. This may be done either by adding further equipment units in these more divisible stages of the process or by "stretching" the capacity of the existing units in these divisible stages, or by a combination of the two.

Either way, this avoids the expense involved in acquiring whole new indivisible units to (expensively) service incremental demands, and also avoids the major expense involved in the disruptions to plant foundation, wirign, layout, materials flows etc. that would be required whenever a very large unit has to be integrated into an existing production scheme.

However, there is an additional aspect of "indivisibilities" to consider which is that in steelplants the smelting, refining and main rolling stages all involve major indivisible units, and these may very easily be out of balance relative to each other. So once the capacity of one of these stages has been reached, then - if output has to be incrementally increased - the only alternative to buying a new indivisible unit and causing major plant disruptions is to try to "stretch" the capacity of the indivisible unit(s) in the stage which is now limiting the plant's output. In other words, initial design imbalance between the plant stages which contain the most indivisible units will eventually lead - as output is increased - to strong capacity stretching signals, in that stage (amongst those with the most indivisible units) which has the least capacity.

Next, quite apart from the imbalances between plant stages which result from the initial plant design, there are several factors which tend to continually create and recreate imbalances between the various stages of the process.

One such factor is the "uneven" character of exogenous technological progress in the industry. All plant stages are of course open to exogenous technological progress. Indeed, the great variety of technological processes in the industry b/ assures that innovations across a broad range of technology may be of use inside steelplants. But it cannot be expected that exogenous innovations will stimulate progress in all plant stages at excatly the same rate. If a plant adopts, for example, a blast-furnace innovation which raises its pig-iron production capacity, this will leave its steel refining capacity unaltered. Similarley adoption of an improved oxygen lance for refining will leave the

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a/ This is the classic problem studied by H. Chenery (1952) 4/, and A. Manne (1967) 5/.

b/ Steelplants incorporate thermal, mechanical, chemical, metallurgical, thermo-mechanical, termo-chemical, electro-chemical processes. As Baloff (1963) 6/ has pointed out "a study of steel processing is... equivalent to studying several machine-intensive industries".

rolling capacity unaltered. Thus the adoption of exogenous inventions may easily "unbalance" an initially balanced set of capacities in successive stages of a plant.

Another factor which creates imbalance is "breakdowns", which are prevalent in steelplants due to the intense thermic and mechanical stresses involved in heating, pouring, shaping and transporting thousands of tons of dense metal per day through the successive plant units. Breakdowns of any duration cause serious bottlenecks, and when a particular stage repeatedly has breakdowns, this can easily lead to a) more intensive preventive maintenance procedures and b) some modifications to the particular main or auxiliary units involved so as to avoid the problem causing the breakdowns, or to make the machinery more robust so as to stand up better to the stresses involved. Both procedures tend to have the effect of "stretching" the capacity of the stage involved, so that it no longer represents a bottleneck.

Thirdly, the "learning by doing" process which plant staff engage in (which we shall be examining in more detail in the next subsection) also tends to gradually and perpetually create surplus capacities and imbalances between successive stages.

Finally, the simple effect of "overshooting the mark" when adding capacities to correct bottlenecks, also leads to the perpetual re-creation of imbalances. This is also called the "see-saw" effect, and it was very common in the plants we studied. The implication is that almost any capacity-stretching initiative (whether originally inspired by external or internal stimuli) is likely to stimulate or induce a further stream of secondary capacity stretching adjustments to correct the new bottlenecks and imbalances that then arise, and so on.

The net result of all these factors, is that imbalances and bottlenecks are a permanent feature of steelplant evolution, even though their locus tends to shift from stage to stage (as well as within stages) as output is increased. Indivisibilities, exogenous iventions, breakdowns, learning-by-doing and overshooting all contribute to the prevalence and constant re-creation an re-location of bottlenecks - and to the corresponding pervasiveness of signals for adding incremental capacity in the bottleneck stage. This is often done by capacity-stretching.

9.3 The effect of learning-by-doing.

Another reason for pervasive capacity-stretching concerns the "learning process" that plant staff engage in with regard to controlling and manipulating the complex set of variables associated with steel processes - which leads gradually up to the attainment of rated capacity and then reaching beyond it.

A point here is that engineers in steelplants (indeed in industrial plants generally) do not have such a rigid, fixed notion of a unit's "capacity" as do economists.

In fact, capacity in the particular idiosyncratic working conditions of each plant a/ is always something that can only be accurately determined in practice once the plant is going; also the highly complex and not 100% determinate nature of steel processes b/ forces plant engineers into a process of "empirical trying out" and feedback so as to get to know the quirks of the process and gradually use the feedback to develop better "heuristics" for controlling and dominating it.

In this learning process, engineers conceive of capacity as something that can be varied by alterations in process conditions, in equipment, or in operating or maintenance methods.

Thus, engineers in steelplants first grope towards achieving "rated" capacity, and then try to grope beyond it by using their experience to suggest the appropiate changes in equipment, settings, procedures, etc. This process is, of course none other than "capacity-stretching". Its prevalence in steelplants can, in the last analysis, be traced back to the inherent complexity of the variables involved in steelplant processes, which challenge the "perfomance-improving-instincts" of the engineers and technicians responsible for operating them.

9.4 The effect of indivisibilities on the timing of conventional expansions.

Indivisibilities and plant economies of scale dictate that "conventional" capital investment geared to continuously increasing demand should take place at discrete intervals of time. Chenery 7/ and Manne 8/ have proven that this pattern is optimum (cost minimizing) for single-stage plants without any adjustment delay in conventional expansion. Thus, the capacity stretching signals that arise during the intervening periods, do not simply depend on steel being an industry in which conventional expansions are characterized by long adjustment delays. The latter factor does have the effect of increasing the intervals between major conventional investments in practice. But these intervals would already be quite long anyway for indivisibility reasons.

9.5 Other incentives to capacity stretching.

In addition to the four "technological" factors mentioned above, which all contribute to the pervasiveness of capacity stretching in steel plants, several further incentives to capacity stretching clearly exist. For example some were

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a/ Actual process conditions that characterise individual steelplants are idiosyncratic because of innumerable variations between plants in terms of different equipment and raw material characteristics, distinct grades of steel being processed, different size-ranges of intermediate products, variations in operating practices and end-product specifications etc.

b/ The inherent complexity of process variables and the lack of precise theoretical models to describe what is going on in blast furnaces, steel furnaces and rolling operations means that a great deal of empirical knowledge and experience needs to be gained so as to control them efficiently.

already noted earlier in Section 6.

Below we simply list, without discussion, several of the further incentives which a complete theory of capacity-stretching would need to take into account.

a) Investment constraints produced by financial crisis in steel firms. (May be caused by poor management or by the effect of government measures such as price-controls on steel products, or unexpected sharp devaluations which greatly increase the burden of firms' hard currency debts).

b) Investment constraints due to refusls of relevant institutions to financie conventional expansion projects, even though the firm itself is financially sound.

c) Macroeconomic uncertainties: a low-risk policy when demand is very variable, even if on the average it is growing.

d) Trends in technology: may be useful to delay investments while some emerging new technologies prove themselves.

e) The "spin-off" effects in terms of capacity-stretching of technical changes carried out primarily with other objectives in mind (e.g. to reduce production costs or improve product quality).

f) The need for capacity-stretching as a pre-condition for securing cost reduction of the "Hollander" variety achievable through greater output levels.

g) The fact that experience and skills gained in the process of capacity-stretching can prove extremely valuable in leading to improved plant-design and faster construction and start-up when the firm undertakes its next conventional expansion.

h) The fact that the "objective function" of some steel firms in certain periods may be to maximise output rather than profits.

References to Section 9

1/ R. S. Eckhaus, "Absorptive Capacity as a Constraint due to Maturation Processes", in J.N. Bhagwati and R.S. Eckhaus (eds.), Development and Planning in honour of Paul Rosenstein Rodan, M.I.T. Press, Cambridge, 1973.

2/ N. Baloff, Manufacturing Start-up: A Model, Ph. D. Stanford University Press, 1963.

3/ P. Maxwell, 1st-best Technological Strategy in an Nth-best Economic Context, BID/CEPAL/PNUD, Buenos Aires, 1978.

4/ H. Chenery, "Overcapacity and the Acceleration Principle" Econométrica, January, 1952.

5/ A. Manne, (Ed.), Investment in Capacity Expansion: Size Location and Time Phasing, George Allen and Unwin, 1967.

6/ N. Baloff, op. cit.

7/ H. Chenery, op. cit.

8/ A. Manne, op. cit.

10. CAPACITY STRETCHING ALONG THE ADJUSTMENT PATH OF THE FIRM

The empirical findings reported in Section 5 and the discussion in Section 9 have shown that a major stimulus towards capacity stretching derives from the existence of an adjustment delay in conventional capital intensive expansion. A once and for all upward shift in demand will eventually lead a steel firm to a new long run equilibrium involving an additional and/or a bigger plant. But since this takes time, due to the adjustment delay and to other factors (securing government approval, finance, etc.) capacity stretching may represent a rational response in the medium run. a/

Assume a single producer being in long-run equilibrium at point A of Figure 1, where marginal revenue MR_o equanls both long run marginal cost LRMC and short run marginal cost SRMC. The amount of output produced is q_a. This output is produced by a plant whose average (short-run) cost curve is ^{a}SRAC, which is tangent at point α to the long run average cost curve b/. Assume a once and for all increase in demand which leads to a shift in the marginal revenue curve from MR_o to MR_1. The long run equilibrium position of the firm is D,at the intersection between MR_1 and LRMC. This position will be attained afeter θ periods, where θ is the adjustment delay required for operating the most efficient plant associated with the new equilibrium level of output q_d.

What is the optimum behaviour during the adjustment period?

Conventional theory would state that the firm should continue using the old plant but at higher capacity levels, i.e. by adding variable factors such as raw materials and labor. This would lead us to point B in diagram 1a. The firm would then remain at B from $t = 0$ to $t = \theta$ and then would jump to D. (i.e., output would jump from q_b to q_b). The alternative possibility suggested by the steel plant case studies is to "stretch" the capacity of existing fixed factors, which means that the marginal operating costs of additional output will decrease

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a/ Capacity stretching does not occur ither in Viner's short-run or in his long run (see Viner 1/). While involving some change in fixed factors and in scale of plant, it is not a change which is the optimal one for the long-run level of output of the firm. We therefore identify capacity stretching as taking place in the "medium run". For expositions similar to our's see Ryan and Pierce 2/ and Vickrey 3/. Whether the long run involves building a completely new plant or the enlargement of the existing plant depends on factors which vary across industries. Viner seems to assume that both alternatives are identical. This is not the case in steel since the desirability of enlarging existing plant may be very limited due to the fact that a lot of the investment is "sunk" (specific to the original plant). This kind of situation is envisaged by Vickrey who states that "one is likely never to have the opportunity, even in the very long run, of making a completely fresh start" (Vickrey, 3/ p. 197).

b/ Notice that q_a is produced by our single producer in a plant whose minimum AC output level (Viner's measure of "scale" of plant) exceeds q_a. This contracts with the long-run of competitive firm having a U-shaped LRAC curve - the equilibrium output level equals the "scale" of the corresponding plant. In both cases, however, the AC of the equilibrium output level at the long run plant is lower than the AC that would be incurred by any other plant.

in relation to their level in an unstretched plant a/. A possible outcome of this stretching would be the "medium range" average and marginal cost curves MRAC and MRMC and output level q_c q_b (both the MRAC and the MRMC excludes the fixed costs of stretching). The term medium range is supposed to indicate that the delay in implementing capacity stretching is shorter than that of implementing conventional capital investment. A stretched plant like the one whown in Figure 1a would anable output to increase more during the adjustment period.

The path of output under both alternatives is shown in Figure 1b. The curves reflect some additional considerations not touched upon till now: i) The new long-run equilibrium output q_d is rarely achieved "in one jump" at point θ on the time axis; rather q_D is built up via a learning curve. Also, since the expansion may mean enlargement or radical modernization of the existing plant, then there is usually a period of lower output from the existing plant whilst it is being integrated into the larger complex. ii) The increase in output under capacity stretching is seldom achieved in one jump; some kind of learning process is involved leading to capacity stretching in a series of spurts.

The shaded are between the two curves is the acumulated increase in output which was optimum to produce, given the particular capacity stretching undertaken. It will depend on the following factors: the additional discounted revenue derived from the higher output levels; the additional operating costs (labor and raw materials) and the fixed costs of implementing the capacity stretching. The final outcome is not shown in the diagram, but the discussion of the previous sections suggests the following: i) that there are a series of capacity stretching opportunities in steel plants: ii) that at least some of them are profitable under a wide variety of cost and demand conditions.

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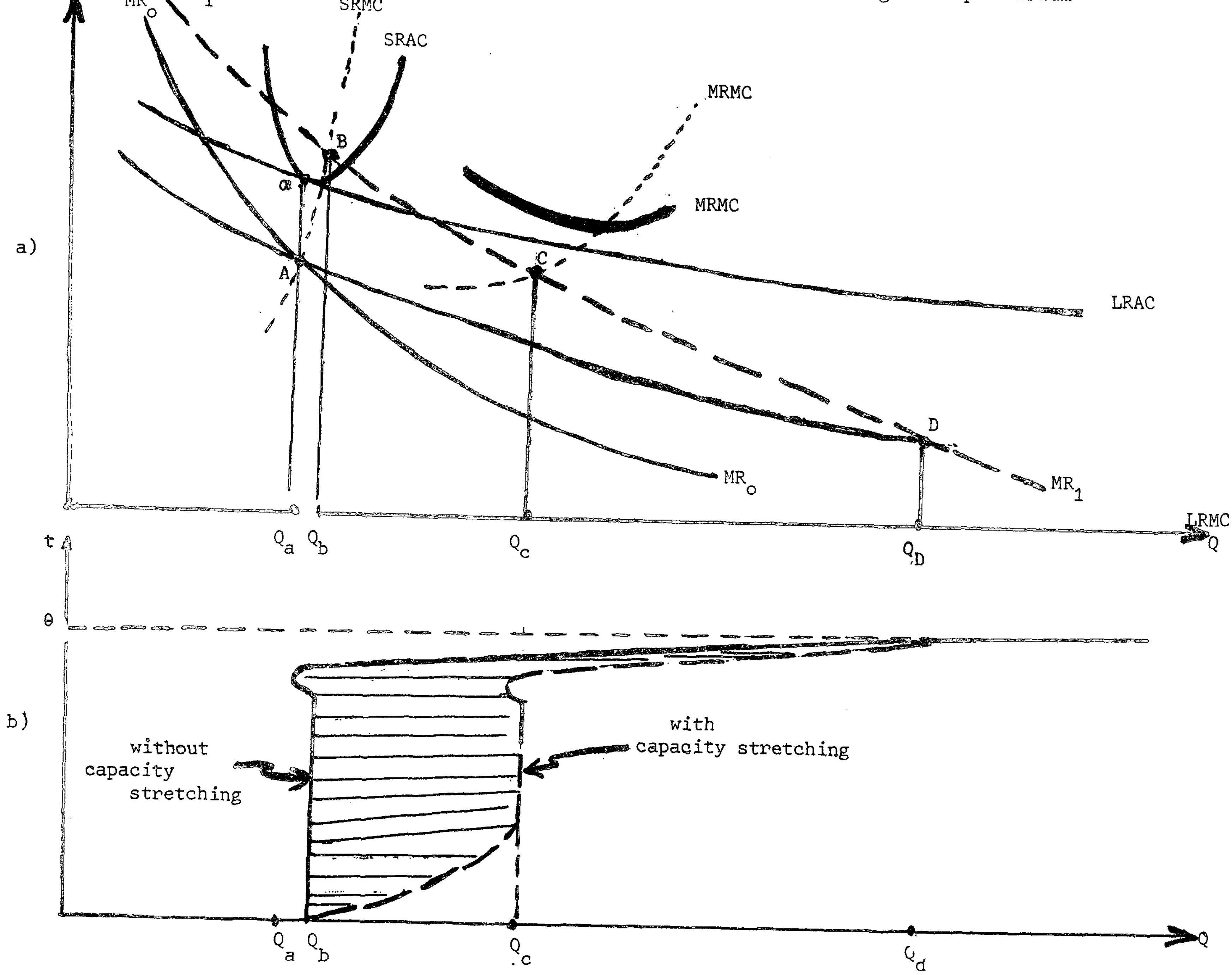
a/ Operating costs do not include the research, development, engineering and capital costs of stretching capacity ("fixed costs of stretching"). They basically include the costs of labor and of raw materials.

Figure 10.1 Adjustment Paths Towards a Long-Run Equilibrium



References to Section 10

1/ J. Viner, "Cost Curves and Supply Curves" in American Economic Association, Readings in Price Theory, George Allen and Unwin, 1953, Ch. 10.

2/ Ryan and Pierce, Price Theory, St. Martins Press, New York, 1977.

3/ W. Vickrey, Microstatics, Harcourt, Brace and World, New York, 1964.

11. THE RELATIONSHIP BETWEEN CAPACITY-STRETCHING AND COST-REDUCING INNOVATIONS

In this section we shall examine how "capacity-stretching" technical changes relate to the more familiar category of "cost-reducing" technical changes. It is alreqdy clear empirically that the two kinds of technical changes are often closely connected. However, as noted in the Introduction, one reason why "capacity-stretching" technical changes have not received very prominent attention in the literature is because they tend to be subsumed as just an aspect or mechanism within the class of "cost-reducing" changes. As a result the literature does not offer much help in discriminating the two kinds of changes. The question therefore arises - what distinctions can be made, and what inter-relations delineated, between these two kinds of technical changes? Or, to put it in a more graphic manner - can these "siamese twins" be separated?

An exercise which we think will be helpful in this regard is to compare what has been reported here about "capacity-stretching" changes with the two main kinds of cost reducing technical changes as defined by Hollander. 1/

The first kind are called by Hollander "direct" cost-reducing technical changes. These are technical changes which act directly on average production costs by reducing input requirements per unit of output even at unchanged levels of output.

The second kind consists of technical changes which are volume-related, and which Hollander calls "indirect" technical changes. a/ They involve alterations to existing machinery or procedures which, alghough they may not result in a decrease in unit costs at unchanged levels of output, nevertheless permit the machinery to function at greater output levels than before - with the result that if this higher level of output is indeed produced, then the fixed costs can be spread over a larger volume of output than before, thus resulting in a decline in unit operating costs. b/

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a/ The following quotations from Hollander are relevant here: "Because of the high proportion of overhead cost, and generally the potential importance of scale economies, a large part of the effort made by research departments has been toward the more intensive utilization of given plant and equipment. Thus the attempts to increase the spinning speed and the denier (in some instances) have been directed towards this end. Similarly, efforts directed toward improved properties of ayon yarn have been, in part at least, influenced by the desire for high output. We refer to development of these kinds as indirect technical changes." "If, as a consequence of increased production, costs per unit fall (relatively fixed items being spread over a greater volume) then the economies will be regarded as the result - albeit an indirect result - of technical change."

b/ Notice that Hollander's "indirect" technical changes are not the same as a third category of technical change observed by Hollander which he called technical changes "induced by an increase of output". The principal example given of this third category is when increased output permits the introduction of more efficient machines which have been known but which only become profitable at new, higher rates of production. Hollander is at pains to contrast these technical

At first glance, Hollander's "direct" cost-reducing technical changes may seem to have nothing to do with our capacity-stretching technical changes. They would seem to be a kind of "pure" cost-reducing technical change. However this is not necessarily so. For, actually, Hollander only defines his "direct" technical changes in terms of tehir effect in reducing costs at unchanged levels of output. It is, however, quite possible to specify several kinds of technical changes common in industrial plants which both reduce costs at unchanged levels of output (i.e. are direct in Hollander's sense) and simultaneously permit or provide increased plant output capacity. (Two examples from steelplants include i) improved process control which leads to increased metallic yield through a lower fraction of defective output and ii) better operational practice leading to more durable refractory linings. These changes not only reduce metal or refractory inputs (i.e. costs) per unit of output but also raise capacity through less defective output in the first case and less down-time for changing refractories in the second case.) In other words, some of Hollander's "direct" cost reducing changes also have a capacity-stretching effect as well.

Clearly, though, it is Hollander's second category - of "indirect" cost reducing technical changes which is closest in spirit to what we have been calling "capacity-stretching" technical changes.

Nevertheless, here too, we can observe that Hollander's definition is somewhat restrictive. For Hollander's "indirect" technical changes produce cost reductions only through their effect on fixed plant costs - by spreading these costs over the larger volume of output that indirect technical changes permit to be produced. In contrast, indirect technical changes are assumed to have no effect on variable plant costs. In other words, Hollander's "indirect" technical changes are a kind of "special case" of capacity stretching changes with no effect on variable plant costs. The restricted range of this definition lies in the fact that it is perfectly possible to visualise capacity stretching changes which do have effects on variable plant costs, either raising them or lowering them. We shall return to this point in more detail below.

Another problem with Hollander's definitions of technical change - which limits their ability to illuminate the capacity-stretching phenomenon - is that he qualified his use of the term technical change by applying it "only to such changes which are brought about by a deliberate decision to reduce costs" 2/ (our underlining). This led him to see, behind every effort to increase output, the intention of reducing production costs. He did not, therefore, discuss the rather straightforward point that efforts to increase output may be a prime

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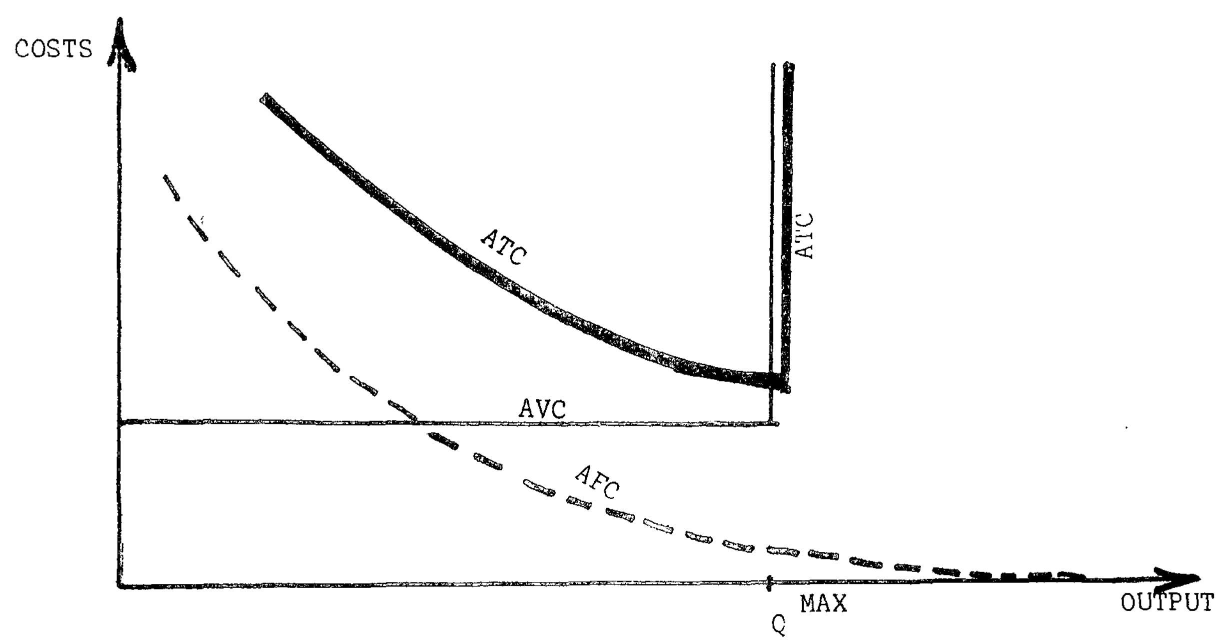
changes which are "induced" by increases in output with "autonomous" technical changes (in which category he presumably includes the direct and indirect technical changes mentioned previously). Autonomous technical changes are not induced by increases of output, though they may cause increased output through lowered prices. In the present context, it seems reasonable to leave out this third category of technical changes from our discussion, because whilst the essence of capacity-stretching is to squeeze more output from existing installed machines, units and plants, the main "output-increase induced" kinds of technical changes which Hollander has in mind involve replacing machines, or sets of facilities suitable at smaller scales of output by new machines or facilities suitable at higher scales of output.

objective in their own right, and may even be undertaken in circumstances when it is expected that production costs will increase as a result of working plants at higher output levels made possible through technical changes introduced to stretch their capacity. Hence "capacity-stretching" changes of a cost-increasing kind do not appear in Hollander's scheme.

To clarify matters, and see more clearly the relation between "the effect on capacity" and "the effect on costs" of given technical changes, we shall put forward the following hypothetical cases based on assuming the existence of plants which have the very simple (but not entirely unrealistic) cost behaviour shown below in Diagram 11.1 below.

Diagram 11.1: Assumed Cost Behaviour in an Unstretched Plant



Quite simply, as output is varied, variable costs are here assumed constant per unit of output until Q_{max} (the maximum feasible capacity of the plant) ia reached, whereupon variable costs are then assumed - for simplicity of exposition - to rise abruptly (become infinite). This explains the behaviour of the AVC (average variable costs) curve shown in the diagram.

The behaviour of average fixed costs, AFC, and average total costs, ATC, is also shown in the diagram.

Let us suppose that a "capacity stretching" technical change is now introduced. What will its effect be on costs?

So far as average fixed costs are concerned it will have no effect in altering the AFC curve shown in Diagram 11.1 - because for the momento we shall ignore the fixed costs involved in stretching (though we will bring them back into the discussion later).

As for its effects on average variable costs, we shall make three hipotheses:

1. That the capacity stretching technical change leaves average variable costs the <u>same</u> as in the "unstretched" plant.

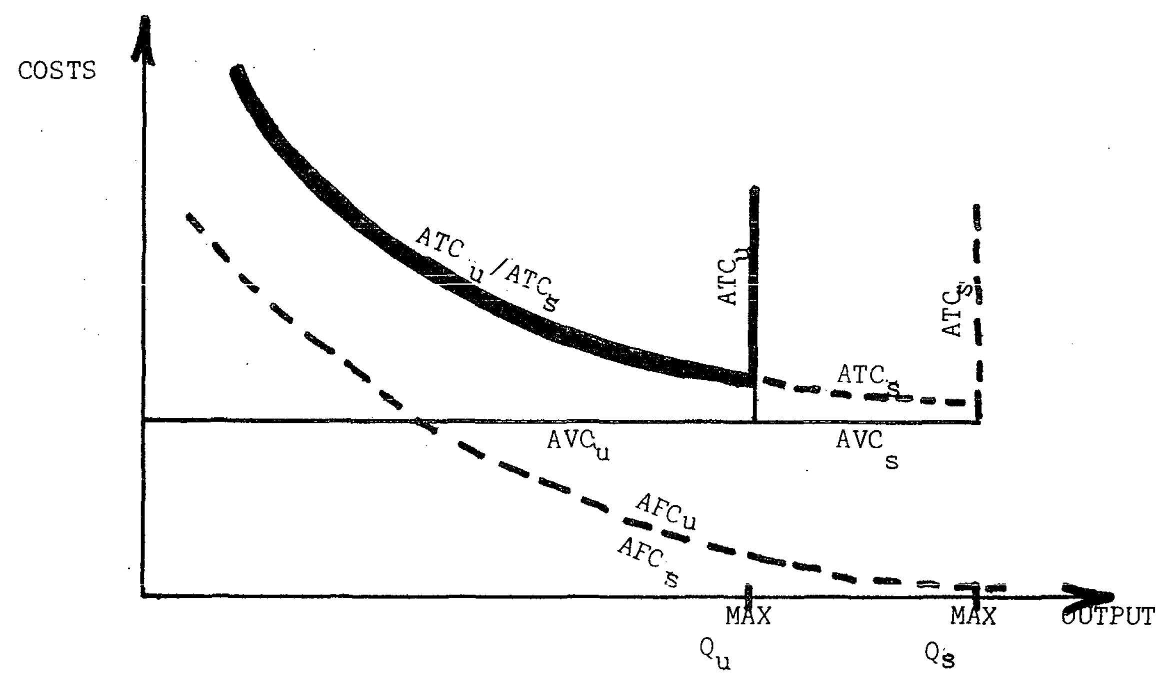
2. That the capacity stretching technical change <u>raises</u> average variable costs above what they were in the "unstretched" plant.

3. That the capacity stretching technical change <u>lowers</u> average variable costs below what they were in the unstretched plant.

The next step will be to depict each of these three hypotheses in diagrams.

First, hypothesis 1. This is shown in Diagram 11.2 below, where the subscript "u" signifies the unstretched plant and "s" the stretched plant.

<u>Diagram 11.2</u>

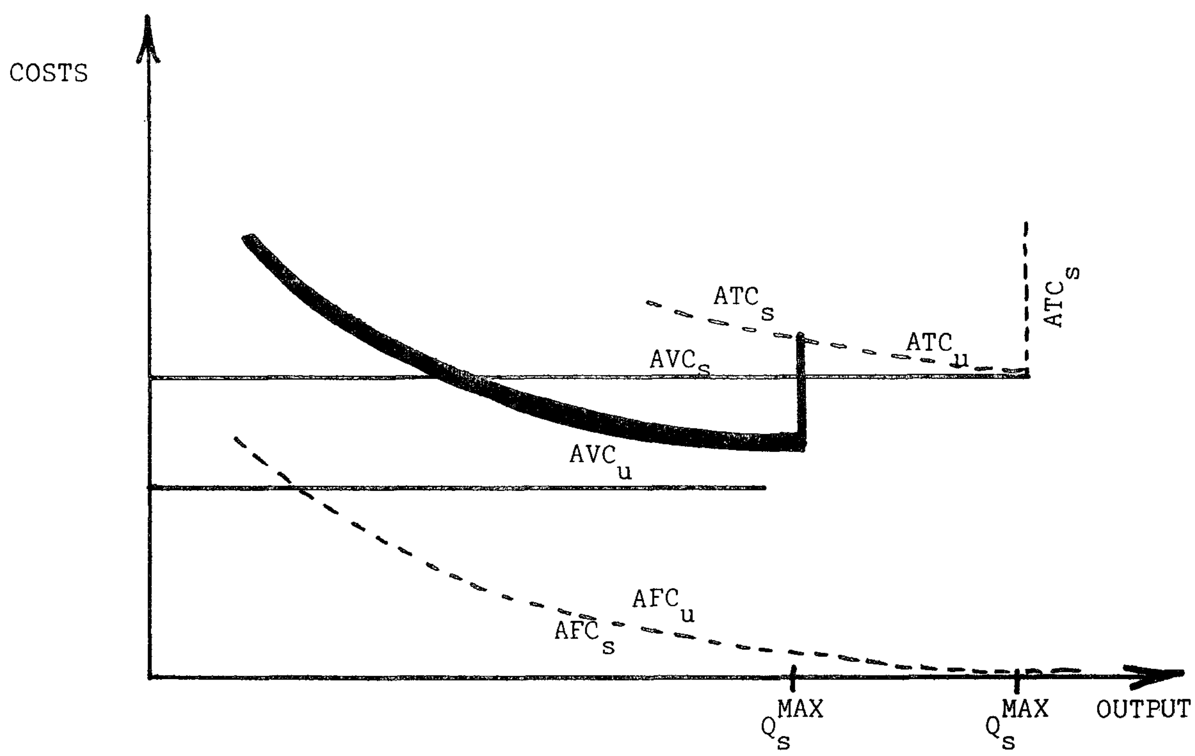


As can be seen, the effect of a "hypothesis 1" technical change is simply to permit the ATC curve of the plant to go on extending downwards towards the AVC asymptote in the zone beyond Q_m^{MAX} which was the maximum output producible in the unstretched plant. It does this, as shown, until reaching Q_s^{MAX}, the limit capacity of the stretched plant.

Furthermore it can be seen how this case is precisely Hollander's "indirect" cost reducing technical change. So long as the output of the stretched plant is greater than Q_u^{MAX} and less than Q_s^{MAX} then this kind of technical change is always cost reducing. At outputs Q_u^{MAX} it is cost "neutral" as costs are identical to what they would have been in the unstretched plant.

Now, hypothesis 2. This si shown in the Diagram 11.3 below.

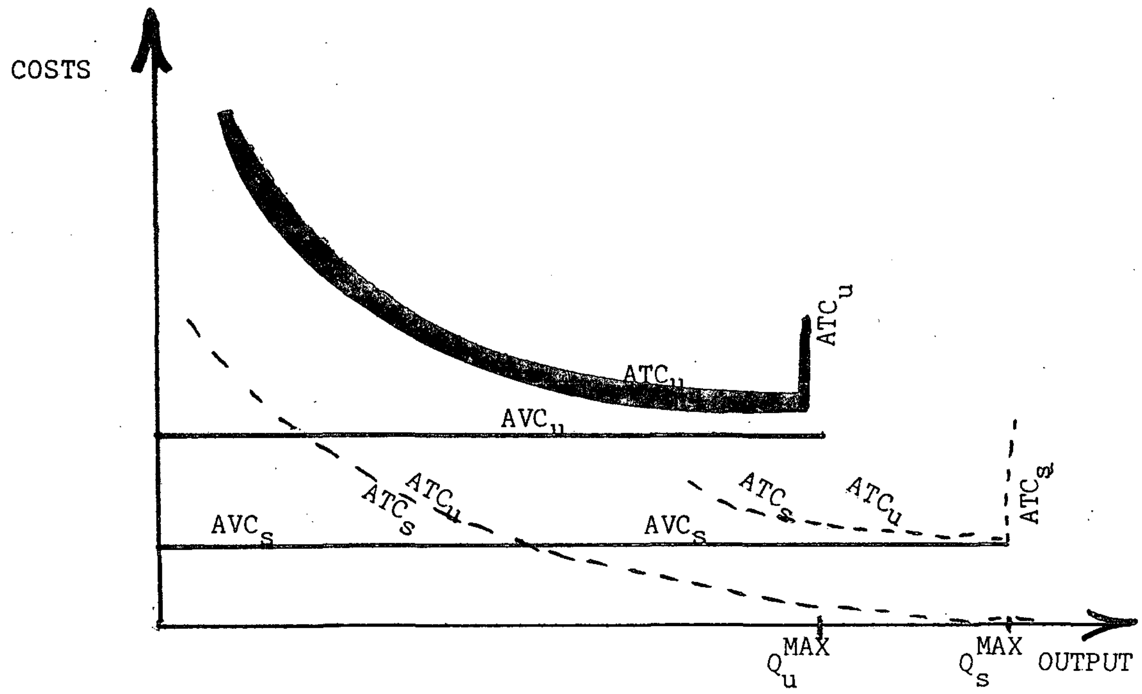
Diagram 11.3



As shown, the effect of a "hypothesis 2" technical change is to raise average variable costs to AVC_s, but to permit the plant to produce at finite costs ATC_s in the region between Q_u^{MAX} and Q_s^{MAX} where ATC_u would have been "infinite". Notice however that this kind of capacity stretching technical change is always cost-incresing compared to what average total costs were at output Q_u^{MAX} in the unstretched plant.

Hypothesis 3 is shown in Diagram 11.4 in the next page, and is simply the opposite to the case shown previously.

Diagram 11.4



It can be seen how - for all levels of output less than Q_s^{MAX} - this third kind of capacity stretching technical change is always cost-reducing, compared to costs at similar output levels in the unstretched plant.

In effect the, the above three diagrams suggest that Hollander's "indirect" cost-reducing technical change can be viewed just as a special case of the broader class of "capacity-stretching" technical changes.

For the simplified kind of cost behaviour shown in the diagrams, the defining condition of a capacity stretching technical change is that it permits a stretched plant to produce - at "finite" costs - in a range of outputs which lies just beyond the "limit" output of the unstretched plan (where, in the unstretched plant, costs would by assumption be infinite).

Now, relax the assumption about a rigid "limit" capacity in unstretched plants, and we can still have a straightforward definition of a capacity stretching technical change: We simply replace Q_u^{MAX} by a "reference output" Q^*. Then we can say that what defines a capacity-stretching technical change is that it reduces the marginal costs of obtaining additional output ΔQ beyond Q^* as compared to what these marginal variable costs would be if this additional output Q was obtained by adding variable factors to the unstretched plant.

Note that this does not necessarily mean, as our "hypothesis 2" case suggested, that ATC_s for producing output Q^*+ Q will be less than ATC_u for producing output Q^*. Whether this will be so, or not, depends on whether capacity stretching increases or decreases average variâble costs in the plant - and also on whether or not any incrase in this latter costs is offset by the fall in average fixed costs that will result from producing a gretater volume of output in the stretched plant.

Until now, we have abstracted from the fixed costs of stretching, but it is obviously important to consider them.

To see the significance of the fixed-cost element in capacity stretching, it is helpful to make a distinction between "successful" capacity stretching and "profitable" capacity stretching. The former saves on variable costs, as compared to adding variable factors to the unstretched plant, when expanding output. The latter implies that the discounted savings obtained more than compensate for the fixed costs of stretching.

If a capacity stretching innovation is average variable cost reducing at a given output level Q^* compared to average variable costs at this same output level Q^* in the unstretched plant then a demand increase may not be a necesaary condition for a capacity-stretching innovation. However, if stretching innovations increase average variable costs at output Q^* then a demand increase <u>is</u> a necessary condition. Moreover, if fixed costs of stretching are high, capacity-stretching, though "successful", may only be profitable under sharp (and sustained) increases in demand.

We should also distinguish a profitable stretching from the "optimum" stretching given new demand conditions. The latter would maximise the profits from stretching. Presumably the sharper the increase in demand, the greater the stretching which would maximise profits.

One further point worth noting is that, throughout the above discussion, we have been asking whether capacity stretching innovations were, or were not, cost reducing compared to costs in an unstretched plant. However one can also ask - are stretching innovations cost reducing compared to costs in a <u>new</u> plant, or in a plant whose capacity is expanded by major investments, not by stretching? We shall not explore this here, however some aspects of this question are tackled in Section 12 below.

References to Section 11

1/ S. Hollander, The Sources of Increased Efficiency, M.I.T. Press, Cambridge, 1965.

2/ S. Hollander, op. cit. p. 23.

12. A MODEL FOR CHOOSING BETWEEN CONVENTIONAL EXPANSION AND CAPACITY STRETCHING

In section 10 we described a situation where both capacity stretching and conventional expansion may take place, but at different time periods: the former in the medium run while the latter in the long run. If we introduce capital indivisibilities into the above analysis it is likely that capacity stretching may be optimum in the long run also, at least for small increases in demand. Whatever the relationship between the two means of output expansion in the long run, it is clear that the conventional expansion decision - its magnitude and timing - is affected by the possibilities of capacity stretching available to the firm. A full blown model should be able to analyse the optimum combination of the two both in the medium and long-terms. In what follows we present a simple model which only considers a once and for all decision of one or the other means of output expansion when the firm is confronted with a temporary increase in demand. In contrast to the previous section where both means of output expansion were complementary, the following model will assume that they are substitutes, i.e., that within the relevant period, either capacity stretching or convenional expansion will be optimum. Although we are aware of the restrictive nature of the excercise we do believe it may represent a useful first step towards a more comprehensive model of the behaviour of firms viz-a-viz cacpacity stretching and conventional expansion.

12.1 Assumptions

Following Teubal 1/ we assume a monopolist facing an increase in demand during T years who makes a decision to adjust by one of two means: capacity-stretching or the addition of new conventional capacity (capital intensive investment). Capital is the only factor of production, and it is assumed to be at the level which maximizes profits at t=0 (the time when the temporary shift in demand occurs and where the expansion decision is taken). It is perfectly sensible and a constant cost of capital r and productivity of capital a, both prior to and after t=0, is assumed. Finally we assume a constant elasticity of demand $\eta>1$. The basic set of equations are the following:

$$Q^d = b_o \; p^{-\eta} \qquad (1)$$

$$Q^s = aK$$

where Q^d, Q^s are quantities demanded and supplied respectively and b_o is the demand level parameter at t=o. From (1)

$$p = \left(\frac{bo}{aK}\right)^{1/\eta}$$

which when introduced into profit function

$$\Pi_o = Q(p-c)$$

(where c is unit cost of production $= \frac{r}{a}$)

leads to the following condition defining K_o - the initial, profit maximizing profit maximizing capital stock:

$$\frac{r}{a} = (1 - \frac{1}{\eta}) \cdot (\frac{bo}{ako})^{1/\eta} \qquad (2)$$

The LHS of (2) is marginal cost while the RHS is marginal revenue.

From (2) we set

$$Ko = \frac{bo}{a} (\frac{a}{r} \frac{\eta}{\eta-1}) \qquad (2')$$

At t=o, the demand level parameter b rises to b_1, for T years

$$b_1 = \mu bo, \qquad \mu>1$$

where μ is the demand shift parameter. Let, $\Pi_1(\theta; r)$ and $\Pi_2(R;r)$ represent cumulated undiscounted profits between θ and T from conventional expansion and capacity stretching respectively. θ is the adjustment delay (starting from t=o) for a new plant of magnitude ΔKo to reach normal capacity $a(\Delta Ko)$ a/. This would be the period of time beyond t=o which would still be required to carry out all the activities related to capital investment: specification of equipment, selection of suppliers, delivery of equipment produced, installation of equipment and start-up. In this model we assume for simplicity that θ is fixed and is exogenously determined (although it is clearly an endogenous variable in part) The main variable affecting Π_2 is R, the expenditures on capital stretching. The productivity of the capital stretching activity can be represented by a function

$$\lambda(R) \; ; \; \lambda' > o \; \lambda'' < o \; ; \; \lambda(o) = 1 \qquad (3)$$

where $a.\lambda(R)$ is the output-capital ratio of 'stretched' equipment.

---

a/ θ here is the adjustment lag for adding conventional capacity rather than that for optimally adapting the structure of the firms total capital to a higher level of output. In this respect it relates more to a planning framework than to the long run adjustment framework described in section 10.

The specific expressions for Π_1 and Π_2 are given by (4). a/

$$\Pi_1 \quad (\theta;r) \quad = \frac{bo}{\eta} \; \frac{\frac{r}{a}\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta}}{\eta-1} \quad T\{\,\mu - \theta\left[(\eta+\mu) - (1+\eta\mu^{1/\eta})\right]\} \tag{4a}$$

$$\Pi_2 \quad (R;r) \quad = bo\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta-1} \; \mu^{1/\eta}\; \lambda(R)^{(1-\frac{1}{\eta})}T - \frac{r}{a}\, bo\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta}T - R \tag{4b}$$

(4a) is <u>maximum</u> profits from capital investment, i.e., it implies that the capital stock has been optimally adjusted to the new level of demand (eq. (2) with bo, Ko substituted by b_1 and (Ko+ΔKo) respectively). That is the reason why Π_1 $(\theta;r)$ is expressed exclusively in terms of parameters of the model. b/ Π_2 $(R;r)$ on the other hand depends on R, a variable whose level the firm must set in order to maximize the profits from capacity stretching. Let R* be the optimum level of R, that is the level which maximizes Π_2 $(R;r)$ from (4b). It is determined by the condition

$$\frac{\partial \Pi_2(R;r)}{\partial R} = 0$$

which implies

$$\frac{d}{dR} \;\; \{\lambda(R^*)^{\,1-\frac{1}{\eta}}\} = \frac{1}{bo\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta-1} \mu^{1/\eta} \; T} \tag{5}$$

$$\equiv B(r)$$

---

a/ The derivation makes use of (1)-(3). See Teubal <u>op. cit.</u> in reference 1/ of this section.

b/ Notice that Π_1 $(0;r) \; = \frac{bo}{\eta}\left(\frac{a}{r}\;\frac{\eta-1}{\eta}\right)^{\eta-1} > 0$

Notice that $bo\ (\frac{a}{r}\ \frac{\eta-1}{\eta})$ is the original "scale" of output or industry size, $bo\ (\frac{a}{r}\ \frac{\eta-1}{\eta})^{\eta-1}$ the original level of sales, and $\mu > 1$ the demand shift parameter. Clearly the greater the magnitude of the variables, the lower the LHS of (5) which implies -given $\lambda''(R) < 0$ (eq.(3))- that the magnitude of R^* is also greater.

12.2 Desirability of capacity-stretching:

This depends on comparing $\Pi_1\ (\theta\ ;\ r)$ of (4a) with $\Pi_2\ (R^*\ ;\ r)$ of (4b) and (5). The condition

$$\Pi_2\ (R^*;r)\ >\ \Pi_1\ (\theta;r) \tag{6}$$

can be expressed as follows

$$\{\lambda(R^*)\}^{1-\frac{1}{\eta}} > A(\theta) + B(r)\,R \equiv X(R;\theta) \tag{6'}$$

where

$$A(\theta) = \frac{\mu+\eta-1}{\eta\mu^{1/\eta}} - \theta\ \frac{(\mu+\eta) - (r\mu^{1/\eta}+1)}{\eta\mu^{1/\eta}} \tag{7}$$

and

$$A(0) = \frac{\mu+\eta-1}{\eta\mu^{1/\eta}} > 1 = A(1) \tag{8}$$

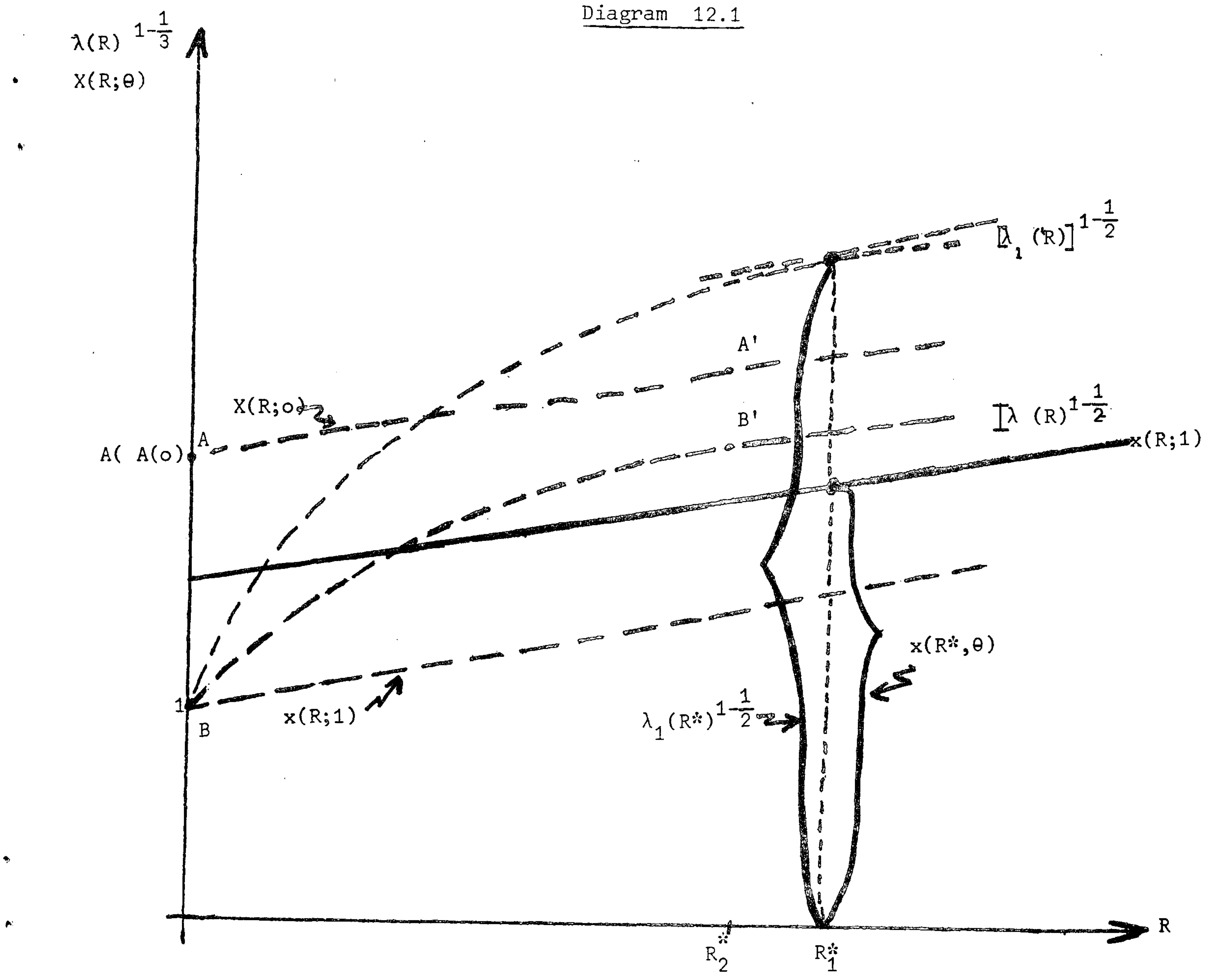
Note that $A'(\theta) < 0$

Condition (6') in conjunction with (5) can be represented in Diagram 12.1. In the vertical axis we measure both $\lambda(R)^{1-1/\eta}$ and $X(R,\theta)$ (the LHS and RHS of (6')) and in the horizontal axis, R. Condition (5) is represented by the equality between the slopes of both of the schedules. $\lambda,(R)^{1-1/\eta}$ shows that capacity when $\theta = 0$.

This follows from $\lambda,(R^*)^{1-1/\eta} > X\ (R^*;o)$.

Since our analysis should not be based on capacity stretching being preferable

Diagram 12.1



$\lambda(R)^{1-\frac{1}{3}}$
$X(R;\theta)$
$[\lambda_1(R)]^{1-\frac{1}{2}}$
A'
X(R;o)
B'
$[\lambda(R)^{1-\frac{1}{2}}$
A(A(o)
A
x(R;1)
x(R*,θ)
1
B
x(R;1)
$\lambda_1(R^*)^{1-\frac{1}{2}}$
R
R_2^*
R_1^*

to conventional expansion in the absence of a positive adjustment lag, the relevant capacity stretching schedules should avoid cutting the X(R,0) schedule for below (see the $\lambda_2(R)^{1-1/\eta}$ schedule of the figures). Thus a necessary condition for prefering capacity stretching is $\theta > 0$. a/ Under our assumptions, the possibility of capacity stretching being the preferred action positively depends on the following factors:

i. The eficiency of capacity stretching.

ii. The scale of output over which the stretching is applied - a magnitude which under our assumptions directly depends on the demand parameters b_o , μ and η.

iii. The adjustment delay to conventional expansion, θ.

iv. The period T for which the higher demand is expected.

We also note the following:

Proposition 1:

Whenever capacity stretching is the preferred response to a temporary increase in demand the optimum expenditure increases with the efficiency of capacity stretching and with the level of output of the industry.

Proposition 2:

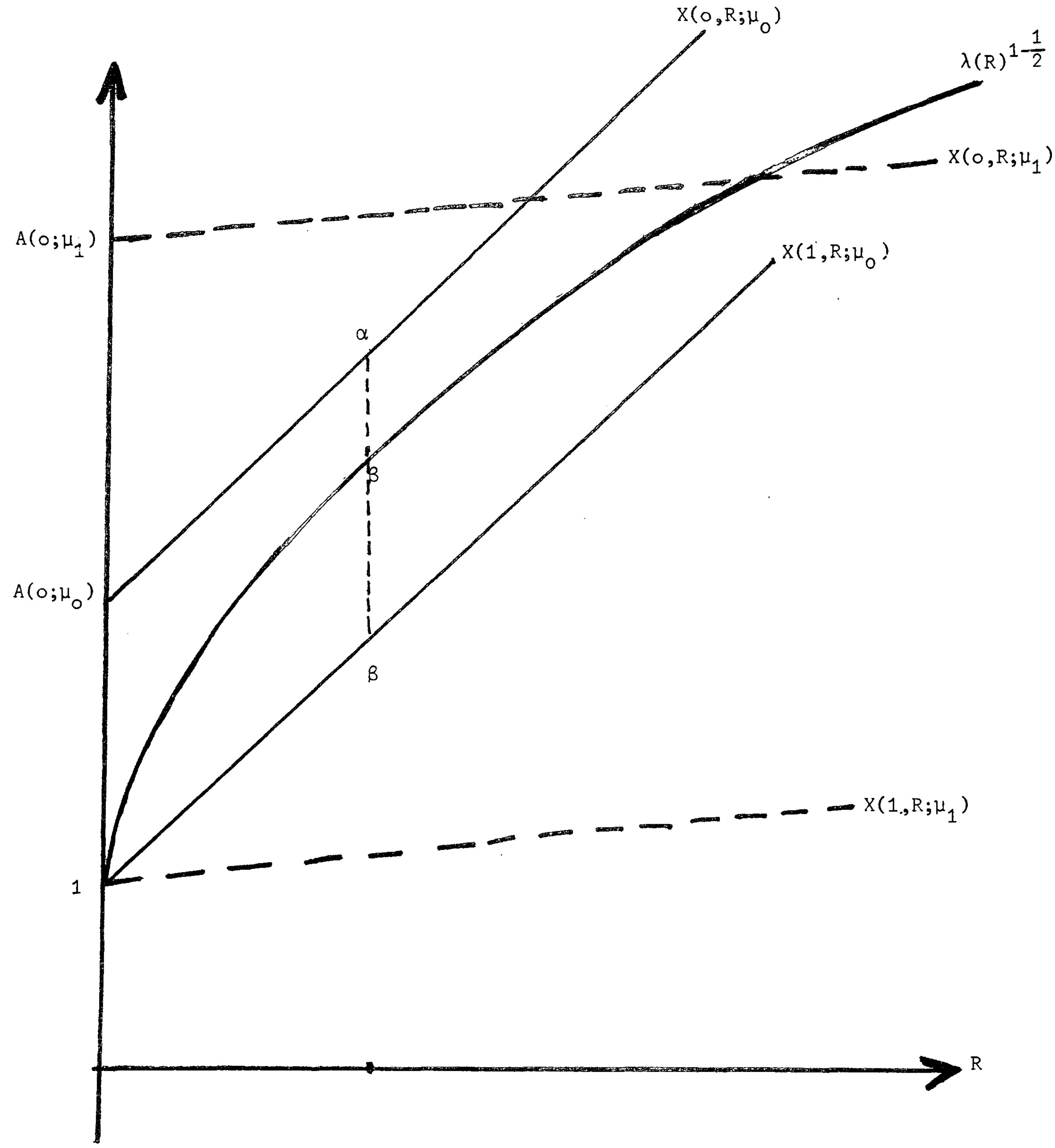
The minimum delay to conventional expansion above which capacity stretching is the preferred response to an upward shift in demand decreases when the magnitude of the demand shift increases.

Proposition 1 follows directly from the Diagram. An upward increase in the original sales level of the industry $b_o\left(\frac{a}{r}\frac{\eta - 1}{\eta}\right)^{\eta-1}$, in the demand shift parameter μ or in the time horizon T will reduce the slope of the $X(R,\theta)$ scheduele and therefore tend to shift R* to the right. Similarly, an upward increase in η or in $\lambda(R)$ will increase the slope of the $\lambda(R)^{1-1/\eta}$ schedule and therefore also tend to increase R*.

With respecto to Proposition 2 note that the minimum delay $\underline{\theta}$ for a capacity stretching schedule $\lambda_2(R)$ is given by the following

a/ One might still argue that when capital investment is indivisible capacity stretching may be preferred even when $\theta = 0$ (especially when demand shifts are small). This possibility, however, is excluded given the assumptions of the model.

Diagram 12.2



$$\underline{\theta} = \frac{X(R_2^* ; 0) - \lambda_2 (R_2^*)^{1-1/\eta}}{X(R_2^* \quad 0) - X\ (R_2^* ; 1)} \tag{9}$$

$$= \frac{A'B'}{AB}$$

see Diagram 12.1

In order to show that a greater demand shift μ reduces $\underline{\theta}$ differentiate the intercept and slope of the $X(R,0)$ schedules with respect to μ {see (5), (8)}.

$$\frac{\partial B}{\partial \mu} < 0 \qquad \frac{\partial A(0)}{\partial \mu} = \frac{(1-\frac{1}{\mu})(\eta - 1)}{} > 0$$

i.e. the slope declines and the intercept increases. This means that the numerator of (9) decreases and the denominator increases, i.e., $\underline{\theta}$ declines.

An extreme situation is described in Diagram 12.2. The pair of parallel lines represent the $X(R,0)$ and $X(R,1)$ schedules for two values of $\mu>1$: μ_0 (the full lines); $\mu_1>\mu_0$ (the broken lines). We observe -as the demand shift parameter increases from μ_0 to μ_1 how the mininimum delay, $\underline{\theta}$, declines from $\frac{\alpha B'}{\alpha B}$ to zero.

This result is not surprising since we assumed that the costs of capacity stretching are constant whatever the scale of output (alternatively, there are increasing returns to capacity stretching) while the costs of conventional expansion are proportional to the magnitude of the expansion sought (constant returns). The conclusion however will also hold along a range of demand shift in the more realistic situation characterized both by increasing returns to scale in conventional expansion <u>and</u> capital indivisibilities. Strong shifts in demand will then be required to reverse the conclusion reached here.

References to Section 12.

1/ M. Teubal. Innovation and Development: Theoretical Issues Emerging from the BID/CEPAL/PNUD Studies. Working Paper N° 33 IDB/ECLA/UNDP Research Programme on Science and Technology, Buenos Aires, April 1979.

13. SUMMARY

1. This paper has had two main aims. First to advance in the empirical description of "capacity stretching" in steel plants. Second to contribute some ideas towards the conceptual and theoretical articulation of "capacity stretching" technical change.

2. These aims arose from observing that though capacity stretching seems to be quite "pervasive" and important at the plant level, it has not received mucha specific attention in the economic literature; not that it has gone entirely unrecognised, but it has usually been relegated to secondary status in discussions of other topics which are considered as central - e.g. cost-reducing technical change, or economies of scale.

3. Empirically, several findings based on detailed case-studies of some Latin American steel plants were reported. The main group of findings included (i) the large cumulative extent of capacity-stretching achieved in several main stages of these plants, (ii) the fact that this stretching has been achieve in piecemeal, incremental fashion over a period of years often at very low investment cost, (iii) that technical change projects with a capacity-stretching impact were pervasive in all the plants, and (iv) that stretched capacity was often the primary, not merely a subsidiary objective in many of these projects.

4. It was also reported that powerful incentives to capacity-stretching in three of the plants had derived from the delaying or blocking over several years of the "conventional" (i.e. capital intensive) expansion plans which the management of all these plants had preferred as their first option in expanding output.

5. Many other incentives to capacity stretching were discovered in these steelplant case-studies. These included indivisibilities in steelplant equipment, bottleneck/imbalance inducements, temporary demand peaks, learning-by-doing with existing equipment, the external stimulus from capacity-stretching innovations developed in other plants.

6. At the engineering level, a "generic" set of techniques (heuristics) for stretching the capacity of steelplant units and stages was identifies, - and given that engineers as performance-improvers are trained to apply heuristics of these and similar kinds, it was concluded that the pervasiveness of capacity stretching technical change in these plants was natural in engineering terms.

7. Both "ad-hoc" and systematic approaches were observed in the plants towards exploiting the capacity-stretching potential of the installations. In general a more systematic approach got adopted over time as the plant technical staff developed both familiarity with, and a more scientific understanding of the processes concerned. In at least two of the plants, capacity stretching potential was greatly underestimated. It was only the fact that blocked or delayed conventional expansion had made capacity stretching repeatedly necessary that led these plants to actually discover and make use of the full stretching potential that was there.

8. Turning to conceptual and theoretical articulation, it was shown how four inherent technlogical features of steel plants (viz. large capital requirements,

great complexity of process, multistage sequential nature of process and indivisibilities) all reinforce each other in leading to multiple incentives to capacity stretching technical changes. Hence capacity stretching is likely to be a common occurence in all steelplants serving growing markets.

9. It was suggested how the incorporation of capacity stretching technical change into the long run adjustment process of a monopolist might be frame by considering capacity stretching as a "medium run" adjustment. Full adjustment of existing plant (or building of new or additional plant) to satisfy a new long-run equilibrium situation takes a substantial time, due to various longish timelags involved in extensively rebuilding or building new plant. In contrast the stretching of existing plant takes much less time and may therefore represent a rational response in the medium run. It was suggested that in the adjustment process to a higher demand both capacity stretching and conventional expansion are complementary, each one taking place in a different term.

10. Also explored was the question of how capacity-stretching technical changes compare and relate to the better known category of cost-reducing ones. It was shown that capacity stretching technical changes require broader definitions than those proposed for cost-reducing changes by Hollander, and also that capacity-stretching technical changes cannot be considered as "cost-reducing" in a global sense. Nevertheless, if fixed costs of stretching are left out of account then the marginal costs of additional output (beyond a specified level) in a "stretched" plant should be lower than what these marginal cost would have been in the unstretched" plant. In this strictly defined sense, all capacity stretching changes must be cost-reducing.

11. A distinction was suggested between "successful" capacity stretching, (which fulfulls the condition just mentioned in the previous paragraph of reducing the marginal costs of additional output compared to in an unstretched plant), and "profitable" capacity stretching in which the discounted profits from stretching more than compensate for the fixed costs of stretching. One can also visualise a further category, "optimal" capacity-stretching which refers to the optimum extent and expenditure on stretching which would be incurred so as to maximise the profits a plant can obtain from a given demand increase.

12. A simple formal model of choice between capacity stretching or conventional expansion in the context of a temporary rise in demand was put forth in the last section of the paper. In this model these two alternatives are considered as substitutes. For simplicity, conventional expansion was assumed to take place at constant cost with an exogenously determined adjustment timelag $\theta > 0$. The notion of a minimum adjustment timelag $\underline{\theta}$ - one which assumes that both alternatives are equally profitable - was put forth. It was shown to depend inversely on the magnitude of the demand shift. Also shown was that, provided $\theta > \underline{\theta}$ the optimal investment in capacity stretching was positively affected the scale of the industry, the magnitude of the demand shift and its duration.

13. It should be obvious that many complications have been left out in the models put forward in this paper. For instance, the output of a stretched steel plant may not be fully homogeneous with the output of a newer plant based on a different technological process. Also our modelling has assumed perfect information about capacity stretching possibilities, whereas empirically the evidence is that these may be underestimated; in fact stretching seems to occur in a sequential "groping" process whereby experience gained at each step of stretching breeds

confidence for the next one. Then again, the fact that the timelag for conventional expansion is, in reality, partly an endogenous variable, would need to be taken into account explicitly in a more sophisticated model. Also attention definitely needs paying to the individisility aspects in conventional expansion, which we have mentioned but no dealt with here. Another aspect not touched on in our paper relates to the function of "stretchable" plant capacity in oligopolistic market structure, where idle or stretchable capacity may be conceived of in entry-preventing terms.

14. Nevertheless even at this stage of development, the findings reported in this paper can be seen to be of some consequence to planning. For they cast doubt on the relevance of two major assumptions made by Chenery, Manne, and many others in the planning literature: first, that production capacity is well defined, and second that adjustment lags are instantaneous. In the previous three sections, we put forth some considerations and simple models which attempt to explain or incorporate these findings. A measure of their success will be in the stimulus they may provide to other researchers in further conceptualizing and modelling the central phenomenon dealt with in this paper.

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